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Editor: Dr David M. Jones
e-mail: journal@ougs.org

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bladed barite (white) mag. 580×; ppl	botryoidal barite mag. 538×; xpl	spherulitic barite mag. 584×; xpl
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Editorial: Curious connections?

Dear OUGS Members,

This is, of course, the bicentennial year of the birth of one of the greatest scientists, indeed one of the greatest humans ever to have lived — Charles Robert Darwin, born in Shrewsbury on 12 February 1809; died 19 April 1882.

It is also the one-hundred-and-fiftieth anniversary of the publication of the book that has changed our way of thinking forever, but over which much dispute and conflict continues to rage: The Origin of Species by Means of Natural Selection or the Preservation of Favoured Races in the Struggle for Life, *to give it its glorious full title.*

I recently re-visited Down House in Kent, the home of Charles and Emma Darwin and their large family, now in the care of English Heritage. In honour of the two anniversaries, English Heritage has put on a wonderful new exhibition within the house and gardens. The exhibition describes and explains Darwin's upbringing, early studies, momentous voyage around the world on HMS Beagle*, the tutelage he received from many of the great scientists and naturalists of the day and, of course, the thinking that led to his great discovery of how evolution in animals and plants works.*

There are video clips of many present-day celebrities and descendants describing 'what Darwin means to them', and a narrative exhibition MP3 player to guide you around and explain the rooms, their contents, the gardens and the experiments that Darwin carried on in them. The narrator is David Attenborough, who has done so much to awaken huge audiences to the natural world, its benefits and perils.

Several key things interested me especially about the new exhibition — some key facts about Darwin that exemplify the man and also go some way to explaining why he was the great man he was.

In the gallery about his voyage on the Beagle *there is mention — from his son Francis' biography of him — of his taking a Bible with him, written in German. It is explained that Darwin was trying to improve his German so as to better exploit the scientific work of his fellow naturalists on the Continent. Francis comments that his father marked in pencil in the margin where he had left off reading previously, and remarks that he was astonished at how few pages at a time that his father was able to read.*

It is a pity that Darwin was not better in German, for had he been, he might have discovered the discoveries of the humble Austrian-Moravian monk, one Gregor Mendel, who published, in German, his findings on breeding, cross-fertilization and inheritance of traits.

Mendel had delivered his findings in the February and March meetings of the Natural History Society of Brno in 1865, and his paper was published in Society's Proceedings. *Thereafter, for several decades, little notice was taken of his work.*

The one thing that Darwin said he 'lacked' in his understanding of natural selection and the origin of species was just what was the 'mechanism' that caused the small, incremental changes driving evolution. It is my firm conviction that had Darwin found out about Mendel's work it would have provided him with what he sought — the essence of just that mechanism. For although Mendel never actually used the word 'gene' — the word was coined in 1913 in an English medical dictionary — he did use the terms 'dominant' and 'recessive', and he established that every seed contained two 'Elemente' (factors), as he called them, one dominant and one recessive, that combined to determine predictable patterns of inheritance.

Darwin's final book — that one on earthworms — was published the year before his death. It was a study that he had conducted for a long time, and that, as you also learn in the exhibition, his children carried on doing for decades after *his death!*

This is another 'key thing' for me. Darwin was, despite the times in which he lived, if anything, the antithesis of the 'Victorian patriarch'. He was so devoted to his family that he involved them all in his work and experiments. He had them playing music to the earthworms; he had them chasing the flights of bees in the meadows; he had them collecting data in the greenhouses; he had them making bespoke scientific instruments for him. And*, he had a splendid, polished wooden 'stair slide' made for them to romp on down the staircase.*

And in his scientific explorations, Darwin never considered anything so unimportant as to be unworthy of his notice and of his straightforward experimentations.

Far from being a stern father, Darwin was an extremely liberal-minded person; and of course, this outlook goes a long way toward explaining why he was, as a scientist, able to 'think outside the box', or to 'think laterally', as we so curiously term it today.

And so this leads me to mention an equally important bicentennial of 2009, for it is also two hundred years since the birth of, in my mind at least, an equally great human — Abraham Lincoln. But not only is this Lincoln's bicentennial year, it is also an exact bicentennial to Charles Darwin.

Yep, thet's reet folks — Honest Abe was born on the same day, in the same year, that Chuck was!

In his own words: "I was born Feb. 12, 1809, in Hardin County, Kentucky. My parents were both born in Virginia, of undistinguished families — second families, perhaps I should say. My mother, who died in my tenth year, was of a family of the name of Hanks... My father ... removed from Kentucky to ... Indiana, in my eighth year... It was a wild region, with many bears and other wild animals still in the

continued on page 5

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Editor's notes to contributors

Following are guidelines for the submission of articles to the *OUGS Journal*. The principal theme encompassed within these guidelines is 'please keep it simple'. Let your editor do his job and please do not try to simulate, emulate or reproduce the page layout of the *Journal*. I have dedicated page-layout software (QuarkXPress) to do this and any special formatting, special characters and embedded illustrations that you include in a word-processing document can be lost (at best) or seriously confuse and crash (at worst) my iMac or the QuarkXPress software when I import it into the layout.

If your article contains special characters (such as mathematical symbols), please draw these to my attention (I will probably spot them anyway) so that I can import them properly with the glyphs menu in QuarkXPress.

Here are the basic guidelines. I will contact you about any queries that arise when I read your article. I will send you an edited version, showing you any changes that I have made and raising any queries or requesting any missing information.

Guidelines for *OUGS Journal* articles

As *OUGS Journa*l Editor I do not want the publication of your paper to be more work than is necessary for you (or for me!). Your paper need not be more than about 1,500 to 4,000 words in general, but I leave the length up to you to suit the material.

Regarding papers from the presenters of lectures at the OUGS Symposium, all OUGS members are grateful to you for presenting a talk at the OUGS Annual Symposium, and for agreeing to submit a version of your talk for publication in the *Journal*. The purpose of this is to make your information available to OUGS members and others who could not attend the symposium. As OU students and OUGS members we enjoy hearing and learning the information these symposia bring to us.

All that is necessary is the following:

• A Word (or compatible) file of the text: There is no need for you to attempt to format the text in any way using tools in Word or other word-processing software. I will do the page layout format in the *Journal* house style, using dedicated publication-industry-standard page-layout software (QuarkXPress). However, feel free, if you wish, to use **bold** and/or *italics* to indicate headings and subheadings so that I can set these into house style.

I do not require a hard copy, but if you need to point out special characters or attributes in your paper, it may be a good idea to send one with these items marked up or otherwise highlighted. Otherwise I can accept electronic files attached to an e-mail, or files on a CD.

• Each illustration, chart, graph, map or other illustration as a separate digital file in high resolution: 350dpi minimum for colour or half-tone images; 1400dpi for line illustrations. Tables composed in Word or Excel are fine, as they are just text. A rough guide to the number of figures in an article is 5 to 10. Obviously as a symposium presentation speaker you might have shown numerous slides, so please use your best judgement on the number to include with the paper to be published — again usually 5 to 10 is a rough guide. *Please note that figures are normally printed in greyscale in the* OUGS Journal*, except Moyra Eldridge Photographic Competition winners.*

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As the author, this responsibility is yours.

• Please do not embed your illustrations in Word picture boxes within the text: All that is necessary is to indicate, by a reference within ( ) or within [ ] in your text, where the illustration should go.

• You can submit the material as attachments to e-mails to me or send it to me on a CD: I am on BT Broadband, so I can receive large files. It is usually best to attach only a few illustration files each to several e-mails. This applies especially to large files of photographs, charts and graphs.

• Where appropriate, cite your sources, or make it clear that a statement is a supposition, or solely your own view or opinion. We use Harvard style citations in the text: (author date, pages), e.g. (Jones 2004, 51–3); and your sources or references should be listed in alphabetical order by author and date at the end of your article. You need to list the author, date of publication (or of access to a web site), full title, periodical volume and number, or place of publication and publisher, and page numbers.

If you miss out anything, I will ask you for it.

If your list includes items not cited in your text, it will be called 'Sources'; if all items in your list have been cited in your text, it will be called 'References'.

That really is it! The editing and page layout are my job, so let me do it for you. I will communicate with you as necessary as I do this, with queries or difficulties with any formats, special symbols, characters, etc, as is the task of any editor.

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The Oxford English Dictionary

The Penguin Spelling Dictionary 1990. London: Penguin Books Ltd

Ritter, R. M. (ed and comp.) 2000 *The Oxford Dictionary for Writers and Editors* (2 edn). Oxford: Oxford U. P.

Ritter, R. M. (ed and comp.) 2002 *The Oxford Manual of Style*. Oxford: Oxford U. P.

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Research and travels of an Argon geochronologist

Sarah C. Sherlock

Introduction

Geoff Brown was the head of the Earth Sciences Department when he was killed by an eruption on Geleras Volcano in 1993. This talk contains material that I hope would have interested Geoff: how to find the ages of igneous and volcanic rocks.

Why potassium-argon dating?

Argon geochronology is one of the most versatile radiometric dating techniques available to geologists. It is based on the decay of potassium (K) to argon (Ar) in nature, and in its simplest form, we measure the ratio of these two elements to determine the age of a rock or mineral. Before 1966, the technique was just that — the measurement of potassium and argon on a rock sample using a different analytical technique to measure each element. Following on from this, 'argon-argon dating' was developed by Craig Merrihue and Grenville Turner (Merrihue and Turner 1966) in the late 1960s. It is a significant improvement on the K-Ar dating method because all the isotopes of Ar that need to be measured can be done so on single and much smaller rock samples, whereas for K-Ar dating the potassium is measured on one aliquot of sample, and the argon on another, using two different techniques. In practice we can now measure isotope ages on small rock and mineral samples, using just one analytical instrument.

Ar/Ar dating is versatile because it is based on the decay of K, which is one of the most ubiquitous minerals on rock bodies in the solar system. It was first used to date moon rocks returned from the Apollo missions (e.g. Turner 1970a, 1970b), a key driver in the development of a technique that could date small, very rare rock samples. Since then it has been used to date volcanic eruptions and meteorite impacts: for example, to date the AD79 event that buried Pompeii (Lanphere *et al.* 2007), to link the Chixculub meteorite event and the major mass extinction event and to date the massive outpourings of flood basalt that occurred at the same time (e.g. Kelley 2007 and references therein).

Areas of recent work

In this paper, Ar/Ar dating experiments from the following are described: basalts from the Faroe Islands (Fig. 1a) and the Isle of Mull in Scotland; plutonic granites and granodiorites from Guernsey (Fig. 1b); and silicic ignimbrites from Tenerife (Fig. 1c).

The reason for wanting to date basalts by the Ar/Ar method is because it is really the only isotope dating method that can be applied to these rocks, even though they are generally very low in bulk potassium (< 0.05 weight % usually). The reasons for wanting to actually find the ages of basaltic eruptions are numerous, and centre around the interaction between volcanic eruption and the atmosphere, and their effects on the environment, especially on vegetation. For example, the basaltic Laki fissure eruption of 1783–4 supplied the atmosphere with an estimated 120 million tonnes of sulphur dioxide, causing extensive acid rain and degradation of environmental conditions for a decade (Thordarson and Self 1993). Further back in Earth history it is apparent that there were massive and long-lived outpourings of basalt, much like the Laki fissure eruption, but unless we know the ages and durations of eruptions we can have no real idea of how they affected the environment, or for how long. This summarises why we need to know the ages of flood basalts.

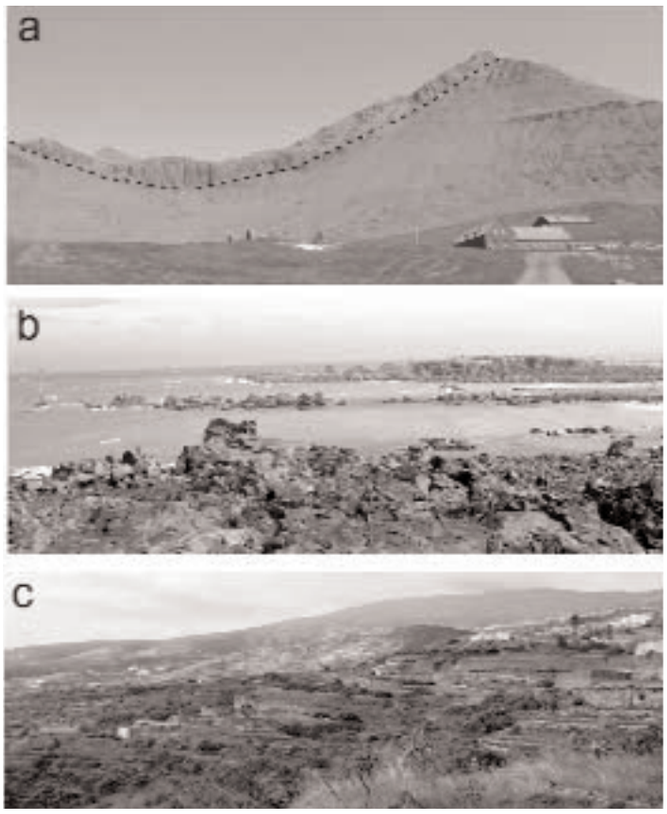

Figure 1 (a) Faroe Islands Basalt Group (NAIP), Streymoy saucer-shaped sill intruding the Malinstindur Formation, Streymoy, Faroe Islands; (b) Cobo granite outcrops and tors, Cobo Bay, Guernsey; (c) Southern Tenerife scenery, Bandas del Sur pyroclastics.

The process

In terms of how we date them, we collect samples in the field and on return to the laboratory the first thing is to make thin sections to assess the freshness of the material and to determine if there are any alteration products within them — for example devitrification of matrix glass to clay minerals, and the replacement of plagioclase by fine-grained micas called sericite. Once we have chosen the freshest samples, they have to be crushed, cleaned to remove the dust, and then the painstaking work of selecting homogeneous 0.5mm cubed pieces using the binocular microscope and tweezers begins. Once we have *c.* 30mg of material, we are ready to send them off to be irradiated. When they return, the pieces of basalt are mounted in a high-vacuum system attached to a mass spectrometer. I will fire a laser through a viewport window, like a porthole in a ship, and melt the sample to liberate all the argon isotopes in the sample. The technique that we use for basalt is the step-wise heating technique, whereby the basalt is heated by the laser, the gases are measured by the mass spectrometer, then the sample is heated to a higher temperature, and the gases measured. Heaitng is repeated until the temperature is high enough for the basalt to have completely melted to a glass

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ball, so there are no longer any argon isotopes left. From the data derived from this process we construct a 'step-heating diagram', which displays the age information. Some good, and bad, examples of this kind of data are shown in the figures (e.g. Figs 2b and 2c).

Dating Faroe Island lavas

The North Atlantic Igneous Province (NAIP) is a large igneous province (LIP) that accompanied rifting in the North Atlantic region during the Late Palaeocene/early Eocene. Today fragments of it are preserved in East Greenland, the Faroe Islands, parts of Scotland and Northern Ireland. It is interesting because it occurred before and during the largest and most sudden increases in global temperature, termed the Paleocene-Eocene-Thermal-Maximum (PETM) event (Jolley and Widdowson 2005). The age of the NAIP has been established through extensive Ar/Ar dating of eruptions in Greenland and the Faroe Islands (Storey *et al.* 2007) and in the Hebridean Islands of Scotland (Pearson *et al.* 1996; Chambers *et al.* 2001; 2005). However, dating basalts accurately is challenging, and there has been a question mark over the ages for the Faroe Island basalts, and their relationship with the PETM.

To describe the paradox briefly, the diagnostic palynofloral assemblage and carbon isotope signature that arises from the PETM in sediments between Faroe Islands basalt lavas occurs in lavas that are thought to have erupted between 60Ma and 58Ma years ago, based on Ar/Ar dating of Faroe lavas. But from other localities around the world the PETM has been dated as occurring between 56Ma and 55Ma. The question is, then, are there actually two separate 'PETM' events — the Faroe Island lavas providing evidence for the first occurrence of an earlier one; or is the Ar/Ar dating or the Faroe lavas inaccurate?

It is well known that there are several processes or sets of conditions that can 'disturb' the Ar/Ar system, such that the Ar isotopes that we measure in the lab are not necessarily the same Ar isotopes that resulted from the decay of K to Ar in nature; and we know that some of these problems occur in basalts. The question is: How we can work out if the Ar/Ar system is disturbed or not? There are several key diagnostics for which we have to test before we can begin the dating measurement process: the first question is, how fresh is the basalt sample? At the outcrop, a sample can appear to be very fresh, meaning that it is free from alteration products, for example, such as chlorite, clay minerals or calcite; under the petrographical microscope the same sample can also appear to be very fresh. However, we have found that putting the same sample under the Scanning Electron Microscope can provide a new perspective; and that at such high magnification it is often apparent that seemingly fresh plagioclase crystals are riddled with < 1 micron clay minerals along their cleavage planes. This phenomenon has quite a stark effect on the Ar/Ar dating system. Another potential alteration product is illite, brought into a rock by warm circulating fluids. When illite or other such products crystallise they can either bring with them their own Ar isotopes, or the circulating fluids can strip out Ar isotopes or K from the plagioclase minerals. Either way, this process will disturb the ratio between Ar isotopes and cause an artificial change in the Ar/Ar age by as much as several million years.

The other key problem that appears to strongly dictate the Ar/Ar age in Faroe Island basalts is the presence of zeolites. Zeolites are microporous aluminosilicate minerals and form through the circulation of warm fluids through a lava pile, and grow at the expense of fine-grained glassy matrix in between plagioclase and olivine minerals (Fig. 2a). In short, zeolites soak up K and Ar that has been stripped out of the basalt and disturb the K and Ar system significantly. Figure 2b is an 'ideal' step-heating diagram, while Figure 2c is a very disturbed example. The idea behind the diagram is to plot the age of each of the step-heating measurements against the % total of released ^{39}Ar in the sample. What we are looking for is for 'concordance' between all the steps in order to derive a 'plateau' age. To do this there must be concordance between at least 50% of the released ^{39}Ar from three or more consecutive steps. While this is true of the data plotted in Figure 2b, which is age data from a meteorite impact crater called Logoisk in Belarus (Sherlock *et al.* 2009), it is clearly not true of the data in Figure 2c, which is from Faroe Islands Basalt Group lavas. Our work in the Faroe Islands is ongoing, and is designed to try to understand how it is best to circumvent the disturbances to the Ar/Ar dating system to obtain the most accurate and precise ages possible for the lava pile. What we have found so far is that the older ages for the lavas that encompass the PETM sediments are those that have the most clay minerals at the finest scale, and the most zeolites in the groundmass, and so we think that these lavas are in fact younger by perhaps a few million years, and that it is the Ar/Ar dating of the lavas that is problematic, rather than there being more than one PETM-type event.

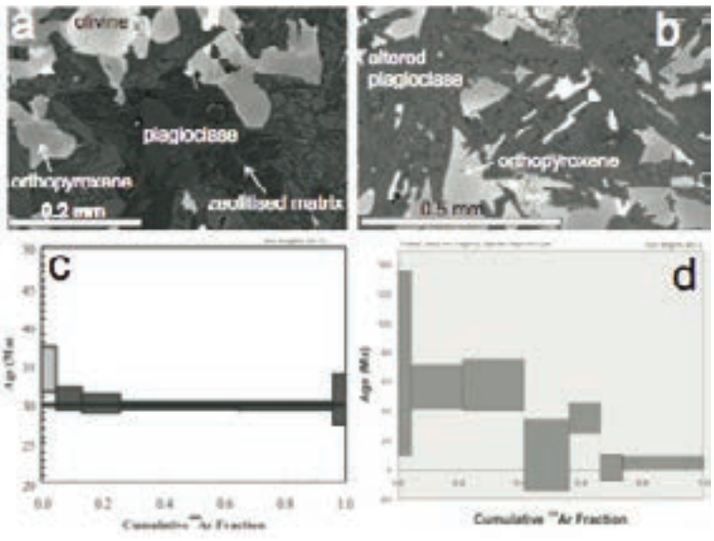

Figure 2 (a) Scanning Electron Microscope image of a Faroe Islands Basalt Group basalt in which zeolitisation of the matrix is a key problem for Ar/Ar dating; (b) fine-grained alteration of plagioclase is also a particular problem; (c) an example of a step-heating spectrum from which a precise plateau age can be derived; (d) an example of a very disturbed step-heating spectrum from the Faroe Islands Basalt Group, from which it is not possible to derive a plateau age (a, b and d courtesy of Alison Halton; c from Sherlock et al. *2009).*

Dating Inner Hebrides and Ireland lavas

The same type of work typifies our research in the Scottish Inner Hebrides. The Isle of Mull is one such study area in which we are trying to understand better the ages of the basalts. Here, the Staff Group lavas contain the diagnostic PETM palynofloral assemblage, and again, the Ar/Ar age dates are older than they should be, the same is also true of the Antrim Basalts in Northern

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Ireland. It is only through very careful sample characterization and Ar/Ar dating and experimentation that we will eventually be able to navigate through the cloudy picture that is the age of the North Atlantic Igneous Province.

Channel Island basement lavas

Moving on to basement complexes, these are the igneous and metamorphic rocks that make up the Earth's crust, and in some cases provide a window into the early crustal growth processes. The Channel Islands are an excellent example of cratonic gneisses and intrusive igneous rocks that are remnant of the Cadomian orogen of the North Armorican Massif. This is an excellent example of Precambrian orogen that has largely escaped tectonic reworking, and so preserves intact early geological relationships (D'Lemos *et al.* 1990 and references therein). Examples of ancient intact basement are rarely preserved and so this late-Precambrian to early Proterozoic orogen, exposed in the Channel Islands, parts of Northwest France, Spain and central Europe. In the Channel Islands, pre-Cadomian basement is represented by the Icart Gneiss. Syn-tectonic foliated granodiorites intruded into the Icart Gneiss have provided age constraints on the initiation of Cadomian orogenesis, while the calc-alkaline Northern Igneous Complex (NIC) of Guernsey were emplaced after the main phase of orogenic activity during the Cambrian-Ordovician. The current model and geological relationships are based on a number of geochronological studies and much of the existing data is providing constraints on the timing of emplacement through uranium-lead (U-Pb) zircon ages, or through whole rock rubidium-strontium (Rb-Sr) isochrons.

My work on the Cadomian, at the moment, extends to the islands of Guernsey and Sark: on Guernsey I have been looking at the ages of the Icart Gneiss (Figs 3a and 3b) and of the post-orogenic Cobo Granite (Fig. 3c); and on Sark, at the Port du Moulin quartz diorite (Fig. 4 *overleaf*).

With plutonic rocks, the technique for analysing them is very different. Samples are prepared as polished 'thick sections' (thin sections but up to 0.3mm thick), which are mounted inside the vacuum chamber. The laser is fired at the surface of the sample, for this type of experiment an ultraviolet laser is used because it delivers a high-energy, but small, beam (0.05mm, for example) that enables the measurement of small areas within individual mineral. My work in the Channel Islands has been, primarily, to develop this '*in situ* intra-grain' dating technique on very old minerals, primarily K-feldspars.

The dating of K-feldspar is actually rather controversial: the mineralogists are of the view that they are so complex in terms of their microstructure that they should be 'leaky' with respect to argon, and it should not be possible to derive any accurate age information from them (Parsons *et al.* 1999). However, I have been able to achieve 'age mapping' of individual K-feldspar minerals, for example, a 0.5mm diameter feldspar will end up with up to 50 individual laser holes in it, each one yielding an Ar/Ar age. It is then possible to contour these ages and produce the 'age map', which I can then use to go on and interpret information about the thermal history of the feldspar. This is very much work in progress and part of an endeavour into technical development of the Ar/Ar dating method, but what I have learnt so far is that, contrary to the conventional view, basement feldspars do indeed preserve age information. The Ar/Ar dating system is not at all 'leaky' and can be of enormous benefit to understanding the thermal history of ancient orogens.

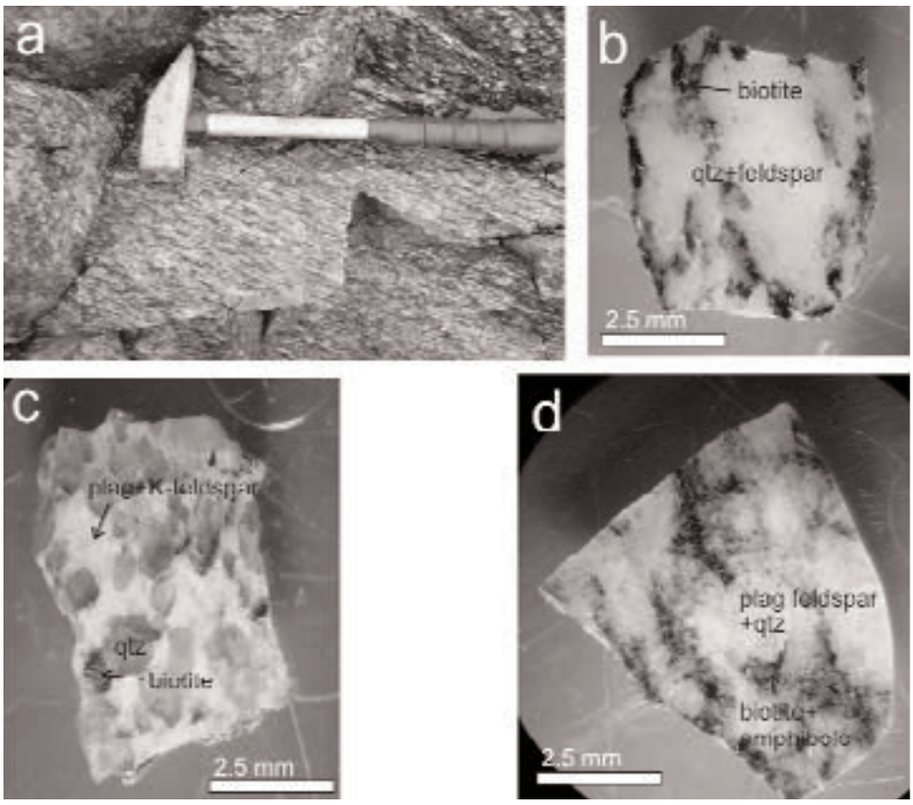

Figure 3 (a) Field photograph of the basement Icart Gneiss, Guernsey. The main foliation is predominantly biotite, plagioclase, minor K-feldpsar and quartz; (b) Photograph of a polished 'slab' of Icart Gneiss; (c) photograph of a polished 'slab' of Cobo Granite; (d) photograph of a polished 'slab' of Port du Moulin Quartz Diorite (b, c and d courtesy of Millie Wilkinson).

Volcanism on Tenerife

The final 'leg' is a foray into silicic volcanism on the island of Tenerife. Tenerife is one of the Canary Islands, an approximately linear chain of intraplate volcanic ocean islands *c.* 100km from the coast of the African continent. Tenerife is the central and largest of the Canary Islands and has experienced volcanism for the past 12 million years (Bryan *et al.* 2002; Brown *et al.* 2003). Before 2Ma, shield volcanism persisted with effusive basaltic volcanism, and from *c.* 3Ma to 0.79Ma volcanism was more explosive, and silicic.

One of the key challenges that we are faced with is determining the ages of these young silicic eruptions. First because they are young, and youthful samples always provide a problem for Ar/Ar dating because less time has passed for the radiogenic decay of K to Ar, and so there is much less Ar to measure. The second problem is one of 'excess argon', this is common to many types of rock but particularly a problem for volcanic rocks. This component of argon, when present, renders the

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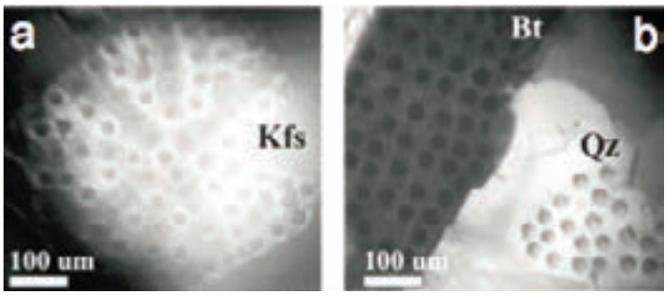

Figure 4 Minerals that have been subjected to the high-resolution ultraviolet laserprobe Ar/Ar dating technique: a) K-feldspar; b) biotite and quartz. Each circular hole is where the laser has been used to ablate that part of the mineral, and has yielded an age.

measured age older than it should be — it is a contaminant that can be dissolved into magma and persist throughout the eruption. It is difficult to detect and impossible to remove, and so in order to understand whether it is there and has elevated the age, we have to measure the ages of as many different components in the rock as are available.

In Tenerife we have been testing this approach on the Bandas del Sur Formation, specifically the Arico Formation (Brown *et al*. 2003). Within it there are obsidian 'cobbles' (Fig. 5a): primarily vesiculated volcanic glass that contain phenocrysts of K-feldspar (Fig. 5b) and of biotite. While the same technique as that used for basalts is applied to these types of rock, rather than melting the 'whole rock' as is the case with basalt, we have to pick out aliquots of the freshest glass (free from mineral phenocrysts), and aliquots of feldspar and of biotite (both of which have to be free from any of the fresh glass that might be stuck to them). The 'step-heating' technique is then applied to the three different types of material, individually, so that we can compare and contrast the data and see which is the oldest, because the oldest samples will be the ones that contain the most 'excess argon'.

What we have found in the obsidian clasts is that the glass contains a large amount of this excess argon, resulting in ages of up to 40Ma (Fig. 5c) for an eruption that erupted less than a million years ago. The biotite and feldspar minerals proved far more reliable and gave us accurate ages of *c.* 0.76 Ma for the eruption.

The next question that we need to answer, however, is why the glass contains so much excess argon and why it did not get lost from the magma on eruption. But this is future work.

Conclusion and acknowlegements

Overall, the work of a geochronologist combines fieldwork, petrography, mineral chemistry, careful (and monotonous!) sample preparation, experimental design — working out which of the many Ar/Ar dating techniques to use — obtaining the data and then finally going on to interpret it, talk about it, write about it and obtain further funding for more research. One of the things that is most satisfying is working as part of a team, and I am no exception. The work that I have described in this paper results from collaborations with many people: Alison Halton (OU) and David Jolley (University of Aberdeen) are gratefully acknowledged for ongoing brilliant collaborations in the NAIP research — Alison's work in particular has prominence in this paper; likewise Trish Clay (OU) is gratefully acknowledged for her hard work in Tenerife; and Millie Wilkinson (OU) and Rob Strachan (University of Portsmouth) for their work in the Channel Islands. Finally and most importantly I thank Simon Kelley (OU), who built up the Ar/Ar dating laboratory at the OU and who has supported me and my work from the start.

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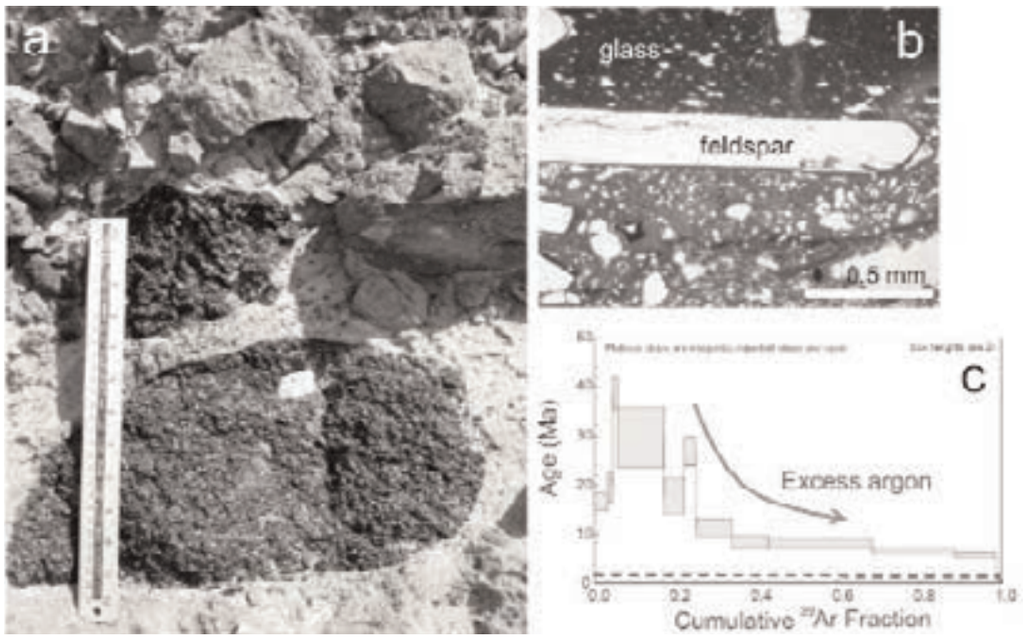

Figure 5 (a) Field photograph of obsidian clasts in the Arico Formation ignimbrite, Tenerife; (b) Photomicrograph of Arico Formation obsidian glass and feldspar; (c) Step-heating diagram for Arico Formation glass — where 'excess argon' is present, it makes the earlier stages of the experiment much older than it should be and diminishes in effect towards the later steps of the experiment (but never totally disappears). For comparison, the dashed line is the age of the feldspars from the same sample (all courtesy of Trish Clay).

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The author

Sarah Sherlock is now a Senior Research Fellow in the Open University Department of Earth and Environmental Sciences, and having completed her PhD there in 1999 she left to carry out research at The Geological Survey of Norway. Sarah returned to the OU in 2000 and has since built up an active group working in Ar/Ar geochronology.

continued from page iii

woods. There I grew up... Of course when I came of age I did not know much. Still somehow, I could read, write, and cipher ... but that was all."

Personally, I find it extraordinary, although not at all astonishing, that two individuals could be born into such opposite circumstances and yet both become such toweringly important people.

Darwin had much to his advantage. He had wealth and a certain 'class' privilege curious to his time, and excellent educational provision. These he did not squander. Rather, his liberal-minded and curious outlook caused him to work around the conventions these circumstances might have imposed, to think and work and discover great things — to think outside the box into which he could have so easily and comfortably crawled.

Abraham Lincoln, on the other hand, grew up in poverty, with little educational opportunity, and yet equally developed an extraordinary thirst to seize whatever learning opportunities he could, and to 'make himself'. The social evolutionary struggle that Lincoln went through made him a liberal-minded man, and a man who passionately believed in the worth of the human race, and humans' right to govern themselves. That was his 'thing', and I find these two individuals — Darwin and Lincoln — much alike in this way'

*If you know nothing else about Abraham Lincoln, you will no doubt associate him with the '*Gettysburg Address*', a short speech he delivered — after the main, and very long-winded and pompous speech of the day by the otherwise unknown Edward Everett — to commemorate, if that is an appropriate word, the fallen at the slaughter known as the Battle of Gettysburg in the American Civil War.*

Lincoln's address was a mere 268 words, of ten sentences, every one of them 'direct and memorably crystalline' in Bill Bryson's words. Lincoln took just over two minutes to deliver his speech. Forget the "Fourscore and seven years ago..." bit. True as this opening sentence is, it is not the heart of what Lincoln wanted to say. For me, here's the essence: "that we here highly resolve that these dead shall not have died in vain ... and that government of the people, by the people, for the people, shall not perish from the earth", for Lincoln never let the world forget that the [American] Civil War involved greater issues.

And therein lies another 'connection' — Darwin also despised slavery, the termination of which Lincoln fought so tirelessly. See a review of the book Darwin's Sacred Cause: how a hatred of slavery shaped Darwin's views of human evolution *by Adrian Desmond and James Moore (2009), in* Scientific American *300 (2), p70 and described in the* OUGS Newsletter *for May 2009, p11.*

Darwin had written, "When I am obliged to give up observation and experiment I shall die." He died, aged 71, in the midst of his fame and, true to his word, continuing the work he had begun.

Lincoln's life was cut short at the age of 56, by a bigot's hand, assassinated on 15 April 1865 as he watched a play. We can only surmise about what further reconciliation and greatness Lincoln would have achieved.

Two great humans, one of whom wrote volumes of clear, dispassionate, understandable prose to help us understand the world, and the other of whom wrote mostly short speeches, but which invariably spoke volumes and help us try to understand how to work within our world.

Let us always cherish and promote the advancement of science and inquiry, if for no other reason, to honour the memories of two of the greatest human beings ever born on Earth — thousands of miles apart, but on the same day in the same year.

Well, that's what I think, anyway.

It is with great pleasure that I wish you 'good reading'.

— David M. Jones, OUGS Journal Editor

PS If you attended this year's OUGS Symposium in Leeds, and partook of the dinner and knees-up you might have seen my own little discovery at Down House — for I was sporting a pair of Darwin cufflinks, bought in the shop!

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Sutures on a shoestring

Severnside excursion to Newfoundland, June 2008, led by Tom Sharpe, National Museum of Wales, Cardiff

Kath Addison-Scott (KAS), Stella Bain (SB), Jenny Davies (JD), Geoff Downer (GD), Nikki Fowler (NF), Janet Hiscott (JH), Bob Jay (BJ), Gill Smith (GS), Gill Toney (GT)

edited by Linda Fowler (LF)

Severnside branch has previously visited Norway, Scotland, Anglesey and the Isle of Man: a visit to Newfoundland led by Tom Sharpe of the National Museum of Wales in Cardiff continued this investigation of geology associated with the Iapetus suture. Tom knows the island well, having been involved in setting up the Johnson GeoCentre in St John's in 2002, and was keen to lead this two week trip. Timing coincided with the last of the season's icebergs and the first of the whales!

The island of Newfoundland lies on the eastern seaboard of North America, in the Gulf of St Lawrence, and is about the same size as England. It has a long history of settlement and we were able to see some evidence of this as well as the geology which was the main purpose of the visit.

*Newfoundland is made up of a series of NE–SW striking terranes accreted some 500Ma ago during closure of the Iapetus Ocean: these represent micro-continents and island arcs caught up in the collision between Laurentia and tectonic plates to the south. From east to west (our initial direction of travel) these are the Avalon, Gander, Dunnage and Humber Zones, with the Red Indian Line (RIL), which runs between subzones of the Dunnage Zone marking the site of the suture.**

4–5 June: St John's and Cape Spear *(JH)*

Twenty-one of us flew from Heathrow to Halifax, Nova Scotia, then onward to St John's, the main town on the Island of Newfoundland.

St John's lies on the Avalon Terrane: Late Proterozoic volcanics and sediments overlain by Lower Palaeozoic sedimentary sequences. Around St John's the Proterozoic rocks were folded during the Avalonian Orogeny before the Palaeozoic sediments were deposited. The whole was faulted and folded during the Acadian Orogeny. The rocks now form a number of eroded domes and basins.

The programme started with a visit to the Johnson GeoCentre [1.2**] www.geocentre.ca/ in St John's, which Tom Sharpe had helped to set up in 2002. It is a modern building built into a natural glaciated hollow and is financially endowed by the Johnson Charitable Foundation. Its director is Paul Dean.

The GeoCentre houses an exhibition explaining the geological history of the Province with excellent specimens of many of the rocks — some are even on loan from the National Museum of Wales! Tom set the scene, giving geological overview and outlining the terranes comprising the island: in the south and east we would be on part of Avalonia and in the west and north we would be on the Laurentian crust. As we travelled across the island we would cross parts of Gondwana before passing over the suture marking the site of the Iapetus Ocean onto the Laurentian crust.

Figure 1 The group on Signal Hill above St John's with Cabot Tower in the background. Leader Tom Sharpe is back row, far left (LF).

St John's, which dates back to 1497, is the main town in the Province of Labrador and Newfoundland. It became established in the 1700s by European fishing fleets visiting the Grand Banks, which lie on the continental shelf to the south-east. Although the fishing industry collapsed in the 1990s following over-fishing, this shallow platform holds the promise of rich oil reserves and commercial exploitation is just commencing. We explored Signal Hill [1.3] and Queen's Battery: the latter overlooks the Narrows, the entrance to the harbour, and also provided clear views of the coast to the south west and offshore towards the Grand Banks.

The oldest rocks on the Avalon Peninsula are the Harbour Main Volcanic Group forming the hills to the west of St John's. Unconformably above this group and younging to the east are the Conception Group (turbiditic sediments and volcanic ash), the St John's Group (shallow marine and delta deposits) and the Signal Hill Group (alluvial, terrestrial deposits), a classic shallowing-up sequence; these rocks are all Precambrian.

The area around St John's is on the Blackhead syncline, formed during the Avalonian Orogeny; the Signal Hill Group (600–550Ma) was folded in the late Proterozoic. Cabot Tower on the top of Signal Hill (Fig. 1) stands on a ridge formed by the Cuckold Formation where the bedding is almost vertical, dipping slightly east. The Cuckold Formation is a red conglomerate but the pebbles have not been identified as being sourced from anywhere on the island. The town of St John's in the valley sits on softer shales and sandstones of the St John's Group, which have

* LF editorial introductions are set in unjustified *italic* text.
** Locality numbers in square brackets [ ] are from 'Geology and Landscapes of Newfoundland', Tom Sharpe's field guide for this trip. The numbers also cross-refer to the on-line images.

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Figure 2 St John's and the harbour, looking west from Signal Hill (JH).

been eroded away by the ice (Fig. 2). From Signal Hill we looked down on ice-smoothed North Head, which is dotted by many erratic boulders. It was here that Marconi received the first voice signal across the Atlantic in December 1901 from Poldhu, Cornwall.

After lunch we drove south-east along the coast to Cape Spear [1.5] — the rocks are still part of the Signal Hill Group, but are on the eastern limb of the Blackhead Syncline. Cape Spear is the mostly easterly point in North America and here we had our first experience of how rapidly the fog can appear, as the lighthouse vanished before our eyes (Fig. 3). This fog is a product of the cold Labrador Current meeting the warm Gulf Stream on the Grand Banks. The Labrador Current also carries icebergs south from the Greenland ice sheet and iceberg spotting became one of the highlights of the trip. In our car we counted 29 over the next two weeks.

Figure 3 Cape Spear lighthouse: mist rolls in from the Grand Banks (LF).

6 June: Ediacaran fossils *(KA-S)*

A day in the SE corner of NFL to see examples of the Avalon Ediacaran assemblage, the oldest of the three global Ediacaran-type fossil clusters and typified by frond-, spindle-, bush- or comb-shaped colonies. We stopped first near Ferryland to see Aspidella preserved beneath sandy turbidites in the Fermeuse Formation, St John's Group. This was first described in 1872 but only accepted as a biological feature in 2000 and occurs in 'unbelievable abundances' (Narbonne 2005). We then went to the southern end of the peninsula to see a range of examples in the Mistaken Point Formation and Drook Formation, Conception Group. The Ediacaran biota now defines the Ediacaran Period (Knoll et al. *2004), which post-dates the latest Neoproterozoic diamictites (Gaskiers glaciation) and predates the Cambrian. Preservation by volcanic ash in the Conception Group aided U-Pb dating and the mega-fossil in the Drook Formation is the oldest known globally.*

For those of us fascinated by the plant-like creatures known as the Ediacaran biota our second day on Newfoundland was a very special one. These organisms represent the first appearance of large and complex life on earth (i.e. the first multi-cellular life), and only appeared after the Cryogenian Period (Snowball Earth); before this only single-celled life is believed to have existed.

We followed the east coast of the Avalon Peninsula, seeing icebergs offshore. Being our first major sightings on this trip even the small ones merited a look. Later we became a bit more blasé, until our last day when, from a boat, we saw two spectacular icebergs up close.

Our first stop was Silos Cove, Ferryland [2.4]. Here the steeply dipping beds (about 85°) of the Fermeuse Formation, St John's Group, dip seawards. The rocks are mudstones and siltstones, finely inter-bedded, which were laid down about 560Ma ago (during the Ediacaran Period of the Late Pre-Cambrian) at the front of a large deltaic system prograding into a marine basin to its south.

The Ediacaran fossils here occur at an unprecedented density of 3,000–4,000 per square metre. Huge numbers of *Aspidella* are present and one cannot fail to find them. They range in size from a few millimetres to 110mm and are the dominant species. Their forms are all disc-like, but vary from flat discs with a central boss (occasionally with a part stalk still attached) to having a raised rim with ridges radiating from a slit. The fossil is probably the holdfast or attachment disc of a frond-like organism.

We lunched in the comfort of the interpretation centre at Ferryland, where there are exhibits of the archaeological finds from The Colony of Avalon, established here in 1621. Excavations exposed house foundations, cobbled paths and streets, a harbour and a smithy.

Portugal Cove South visitors' centre provides informative displays of the types of fossils found at nearby Mistaken Point and the history of the site. We had the good fortune to be accompanied by Richard Thomas (Director of Mistaken Point Ecological Reserve, (www.env.gov.nl.ca/parks/wer/r_mpe/) and Mrs Kit Ward, a local resident (Fig. 4). It has been the locals, and especially Kit, who fought off fossil thieves to protect the site and persuaded the Government to form a reserve. Richard is now attempting to have the site designated as a UNESCO World Heritage Site for its international importance for viewing and understanding the Ediacaran. After a 45-minute walk to the site we removed our boots to examin the 565Ma old seabed — Richard had noticed visible wearing of the exposed fossils and wants to minimise damage (Fig. 5 *overleaf*).

Figure 4 Kit Ward and Richard Thomas tell us about the Mistaken Point Ediacaran fossil assemblage (LF).

The exposure of the Mistaken Point Formation, at the top of the Conception Group, is a 400m thickness of medium-bedded sandstones and mudstones of turbiditic origin. Deposition is thought to have taken place in a fore-arc basin of an island arc and the mudstones are inter-bedded with volcanic ash. The volcanic ash overlying the various beds has been used to date the fossils.

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Figure 5 'Shoeless and clueless' on the Ediacaran exposure at Mistaken Point (LF).

We looked at fossils on two surfaces of that formation, D and E. The lower surface D held fossils of Fractofusus misrai (Spindle), a frond-like branching organism (Fig. 6) and of Bradgatia, an oval or circular branching, bush-shaped organism (Fig. 7).

In the upper surface E, as well as these two species, we also found: *Charniodiscus spinosus*, a holdfast oval shape (Fig. 8); *Thectardis avalonensis*, triangular shape (Fig. 9); *Ivesheadia*, a disc-shaped form with a bubble-like appearance and likened to a pizza base (Fig. 10), the more familiar *Charnia*, leaf-shaped fronds occasionally with a holdfast attached; and an un-named form known as 'feather-duster' (Fig. 6). *Fractofusus* and *Thectardis* are endemic and only a few of the other species are found elsewhere (e.g. *Charnia* and *Bradgatia* in Charnwood Forest, England).

We fnished the day with a stop near Pigeon Cove, in the Drook Formation, lower down in the Conception Group and therefore earlier (dated 575Ma). Here a 2m long specimen of *Charnia wardi* is just visible in the rock. It is only about 5cm wide and looks like a faint bicycle track. This is the oldest reliably dated, and the largest, Ediacaran fossil known. This species either existed before, and survived through, Snowball Earth (580Ma), or underwent rapid evolution after the ice melted. It is fitting that this fossil is named after its finder, Kit Ward's son — all the more special as Kit is one of the locals who has put so much effort into preserving these Ediacaran sites from wanton destruction.

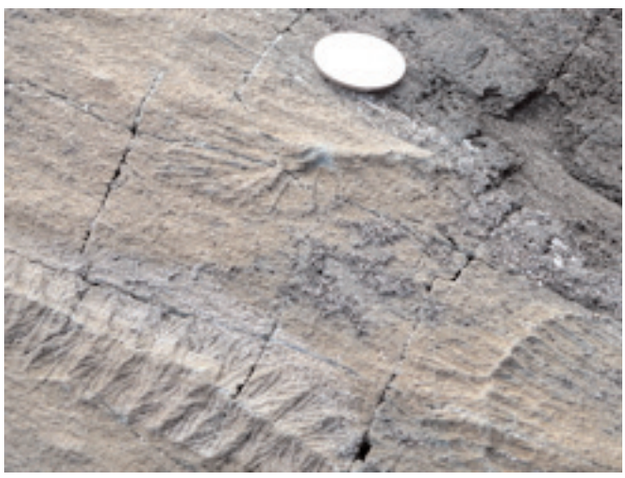

Figure 6 Fractofusus misrai *'Spindle' and the unnamed 'feather duster'; note fragments of gritty volcanic ash, which covered these fossils, aiding preservation (LF).*

Figure 7 Bradgatia *'fan' (KA-S).*

Figure 8 Charniodiscus spinosus*; note the patches of volcanic ash (KA-S).*

Figure 9 Thectardis avalonensis *(KA-S).*

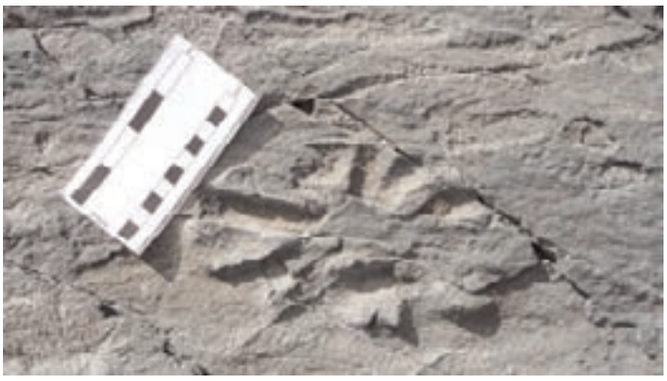

Figure 10 Ivesheadia *'Pizza disc' (LF).*

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7 June: Volcanics and trilobites *(NF)*

A day exploring the structure of the eastern Conception Bay area: from St John's we crossed progressively older rocks of the Conception Bay Anticlinorium before crossing the Topsail Fault onto an upthrown older block: the Harbour Main Group (650Ma) island arc lavas and ashes are intruded by the Holyrood Plutonic Suite (620Ma); unconformably above these are Cambrian rocks including the late Middle Cambrian Manuels River Formation famous for trilobites. Some found by our group included Hypagnostus, larger Paradoxides with long, backward pointing headshield projections, Conocoryphe and Jincella. These, and others seen here, evolved separately from those we saw later in western Newfoundland as they were separated by the Iapetus Ocean. The western Newfoundland environment was equatorial, warm and shallow marine, while eastern Newfoundland was cool, deep water at higher latitude.

Our first stop was a viewpoint in St Phillips [3.7] to look across Conception Bay to Bell Island, *c.* 5km offshore. The island is formed of early Ordovician sedimentary rock, which dips gently westwards. Shales and sandstone are exposed on the eastern side of the island, while the western half has oolitic ironstones, which were mined until 1966. Between the coast of St Phillips and Bell Island is the north-south striking Topsail Fault separating Precambrian rocks at St Phillips from Ordovician ones to the south-west on the islands. Kelly's Island and Little Bell Island are both also formed from the Ordovician Bell Island Group shales and sandstones. To the left of the ferry landing are abundant *Cruziana*, quite obvious trail markings or possibly trilobite burrows. Unfortunately, we were not able to go across to view these.

Along the coast to the north is the prominent headland of Ore Head, whose cliffs are formed of Harbour Main Volcanics (730–650Ma).

Topsail Beach [3.6], our second stop, is a beauty spot. To the left is a gravel bar, known as a *barachois*, which dams the Topsail River to form the shallow bay of Topsail Bight. This back barrier lake is briny and a great spot for birds. To the right our route took us 2.7km across large boulders, pebbles and rocks — Late Precambrian Harbour Main Volcanics. Below the car park, black Cambrian shale dips west beneath Conception Bay towards Bell Island. The straight eastern coast of Conception Bay is controlled by the line of the Topsail Fault, a major structure of the eastern Avalon Peninsula. This fault forms the eastern side of the uplifted, south-plunging Holyrood Horst in the core of the Conception Bay Anticlinorium. The horst itself is made of Late Proterozoic volcanic rock of the Holyrood Intrusive Suite dated 620Ma.

As we neared the fault line below the steeply rising wooded cliff of Topsail Head the dip of the Cambrian shales we had encountered at the car park steepened and their cleavage strengthened. Finally we reached the fault line, marked by a very large quartz vein running N–S along the line of the fault. The fault has moved dextrally and sinistrally, reversing its movement from the Late Proterozoic into the Middle Cambrian; its estimated throw is 7–10km.

After lunch in the sun we moved on to Manuels River [3.4] (ww.manuelsriver.com/), which has beautiful riverside trails besides being a good place for geology. We walked upstream alongside the river to stand on granite from the Holyrood Plutonic Suite in the riverbed. The granite, dated 620Ma, intrudes volcanic ashes of the Harbour Main Group. Returning downstream we found this granite is overlain unconformably by coarse granite pebble and boulder conglomerate of late Lower Cambrian age. This is thought to be a beach deposit formed as sea level rose, spreading over the eroded Proterozoic landscape. The conglomerate is *c.* 6m thick and dips gently to the north-west. As we followed the trail farther downstream the rocks were progressively younger, ranging through green-grey and red mudstones or shales to grey-black, fossil-bearing shales of the Manuels River Formation. We were able to look for fossils although no collecting was permitted. However, we were told that if good specimens were found, then we should bring them to the Manuels River Natural Heritage Society visitors' centre for possible display. We all got our heads down to try to find any tiny bit of trilobite. Whole specimens were unlikely but that did not stop us from trying and we found a number of fragments of various species (Fig. 11).

At our final stop of the day, Kelligrews Quarry [3.3], however, here we were allowed to collect to our hearts content. The Manuels River Formation is more accessible here: shales contain brachiopods and tiny blind agnostid trilobites, and a distinctive orange weathered limestone is full of trilobite fragments (Fig. 12).

Figure 11 Agnostid trilobites, Manuels River, Conception Bay; the largest in this image is c. *15mm long (LF).*

Figure 12 Conocoryphe sulzeri *— Kelligrews quarry, Conception Bay (LF).*

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8 June: West on the Trans-Canada Highway *(JD)*

We drove from the Avalon Zone across the Dover Fault onto the Gander Terrane. At the western side of the Gander terrane we crossed the GRUB line (see below) onto the Exploits Subzone of the Dunnage Terrane. This subzone, which equates to the Southern Uplands in Scotland, is separated from the Notre Dame Subzone (≈ Scottish Midland Valley) by the Red Indian Line marking the Iapetus Suture. The terranes east of the Red Indian Line derived from Gondwana, those to the west from Laurentia. The western edge of the Dunnage Terrane is the Baie Verte Line (≈ Highland Boundary Fault), which separates the Notre Dame Subzone from the Humber Zone.

We set off west from Clarenville on the Trans-Canada highway (TCH) to cross the ancient Iapetus Ocean. Our 550km route crossed a series of terranes moving from Gondwana in the east to Laurentia in the west. Initially we travelled through miles of boreal forest — the silver birch were just coming into leaf — to reach the Terra Nova National Park.

We stopped first to view the Dover Fault, just south of the highway near Maccles Lake [5.1]. This fault marks the boundary between the Avalon and Gander terranes. The Gander terrane docked in a series of angled collisions rather than one simple collision and movement along the fault crushed and recrystallised the fine sediments and granites forming mylonites with fold structures. The exposed surface here also exhibited superb glacial striations striking E–W. We made two brief stops along the highway to view the boulder-strewn valley of the Gambo Brook (Fig. 13) at Joey's Lookout [5.3] and the banded gneisses exposed in a road cutting at Square Pond [5.4]. The collision of the two terranes produced these fairly high-grade metamorphic rocks and subsequent retrograde metamorphism gave the nice examples of epidote and green schist found here.

Figure 13 Joey's Lookout: glacial erratics litter the Gambo Brook (LF).

On the gravel beach of Gander Lake [5.5] we saw bands of blackish-green serpentinite and exposures of gabbro. This Gander River Ultrabasic Belt (GRUB) Line is a classic example of obducted ocean floor and marks the boundary between the Gander zone and the Exploits subzone of the Dunnage zone to the west. Farther across this subzone, in a road cutting at Bishop's Falls [5.6], we viewed red sandstones with clearly visible cross stratification and ripples of various dimensions. At the Red Cliff railway overpass [5.7] in the Ordovician shales we found several samples of 10–20mm long graptolites with indentations clearly visible on both sides. These graptolites probably lived in a back-arc basin associated with the Iapetus closure.

Travelling northwards from Badger on the TCH we followed the Red Indian Line. This contact between the Exploits subzone (which correlates with the Southern Upland Terrane in Scotland) and the Notre Dame subzone (which correlates with the Scottish Midland Valley Terrane) is the Iapetus suture. By the time we stopped at Roberts Arm [5.8] to view the pillow lavas we had finally crossed from Gondwana to Laurentia.

9 June: Gros Morne National Park and The Tablelands *(GS)*

Shallow Bay Motel was our base for two days in the Gros Morne National Park, the first in the Bonne Bay area and the second farther north. This National Park has been a UNESCO World Heritage Site since 1987 because of the international significance of its geology, especially the Tablelands. The Gros Morne rocks are a classic example of obducted oceanic crust and associated structures that date from the Taconic Orogeny in the Middle Ordovician, when a slice of Iapetus ocean floor was thrust, on the Long Range Thrust, over the autochthonous shallow marine rocks of the Laurentian margin to the west.

In 'pouring drizzle', deteriorated to 'pouring rain' we set off towards the southern end of Gros Morne National Park, with various planned stops. The cloud was so low that we could not actually see much of the hill tops.

We first visited Lobster Cove Head [6.1]. Here we viewed dolomites and ribbon shales of Ordovician age — part of a large block of the Rocky Harbour Mélange. Farther around the head we came to greywackes of the Lower Head Formation, containing grains of Tablelands rocks and chromite. These sediments were deposited in the foreland basin created by the weight of the advancing obducting ophiolite that now forms the Tablelands. Scattered on the foreshore of Lobster Cove were glacial erratics.

At the Gros Morne National Park Visitor Centre (www.pc.gc.ca/pn-np/nl/grosmorne/index_E.asp), our next stop, we watched a 20-minute film about the National Park. It was very informative and included the area's history together with breath-taking views over the park during summer and winter. The areas we would not be visiting during our trip were there to be seen in all their glory – shame we had not booked for a month!

Our next stop was the Southeast Hills to view a sequence of sedimentary rocks dipping west. These are part of the Bradore Formation: the lowest unit of the Cambrian succession unconformably overlying Proterozoic gneiss of the Long Range Complex. Next we headed farther south and stopped at a road cut east of McKenzie's Brook [6.2] showing a broad anticlinal structure of exposed sheared and deformed black shales overlain by sandstones and chaotic conglomerates belonging to the Bonne Bay Group (part of a series of lower thrust slices when the Humber seaway closed).

Through the gloom ahead of us we could finally see the sides of the Tablelands — our destination.

The Tablelands are most astonishing: a yellow-coloured plateau almost devoid of vegetation. They are thought to be an upthrust slice of upper mantle and now rise up to 700m above sea level (Fig. 14). They are composed of peridotite which, being

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Figure 14 Our group trekked to Winterhouse Brook in the Tablelands; the peridotite has weathered to a ginger-brown colour and there is very little vegetation (LF).

magnesium-rich and nutrient-poor, does not support much plant growth. The peridotite has weathered to a sandy brown colour, with evidence of serpentinite on some freshly exposed surfaces (Fig. 15). In little niches between the weathering rocks we found Pitcher Plants (Fig. 16), Saxifrage, Bird's Eye Primrose, Alpine Campion and Sandwort eking out a hard existence. As the weather lifted and we had a wonderful view along the road as we headed west — to the left the yellow, barren Tablelands and to the right the vegetated hills of obducted ocean crust gabbros and granites.

As we headed 'home' we had one unexpected stop — to watch a mother moose and her calf wading across a shallow lake — a beautiful sight, and our first 'confirmed' moose sighting!

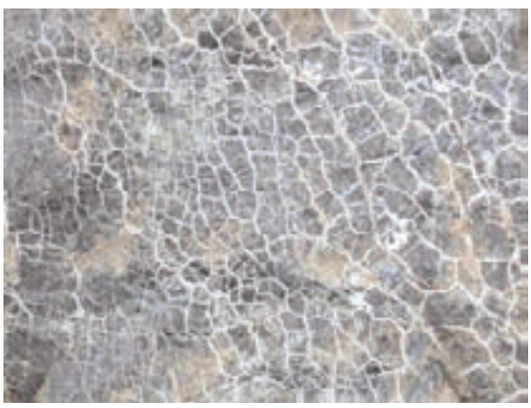

Figure 15 Serpentinite on a peridotite joint surface (GS).

Figure 16 A Pitcher Plant, Newfoundland's national flower (GS).

10 June: A global stratotype section and Western Brook Pond *(SB)*

The first stop was at a unique site — the 'Golden Spike' at the Cambrian-Ordovician boundary, which is contained in now overturned turbidity current deposits from the Iapetus Ocean continental rise. The sediments were later thrust westwards during the Taconic Orogeny and lie beneath the Tablelands ophiolite. Western Brook Pond is a freshwater fjord, originally cut by glaciers that reached the sea, but are now cut off from the ocean by isostatically rebounding sea floor. The Pond is 16km long, between 4km and 1.5km wide; cliffs of 1000Ma old metamorphic and igneous rocks, remnants of the Grenville Mountain Belt, rise 700m above its surface and are cut by dykes dating from the breakup of Rodinia c. *650Ma ago.*

In another day of sun and clouds, we visited Green Point [7.1], where thin beds of shale and limestone are exposed along with a few limestone conglomerates. This very significant site is the Global Stratotype Section and Point for the base of the Ordovician System (Fig. 17) (www.stratiugraphy.org/green.htm). The boundary of the Cambrian-Ordovician is defined by the first appearance of a specific type of micro-fossil — the conodont *Iapetognathus fluctivagus*. Although we did not find conodonts we did find some graptolites, including *Rhabdinopora* (Fig. 18). We then progressed to Broom Point [7.2], where we saw the preserved fish shed and cabin that had belonged to the Mudge family who ran an inshore fishing operation here between 1941 and 1975.

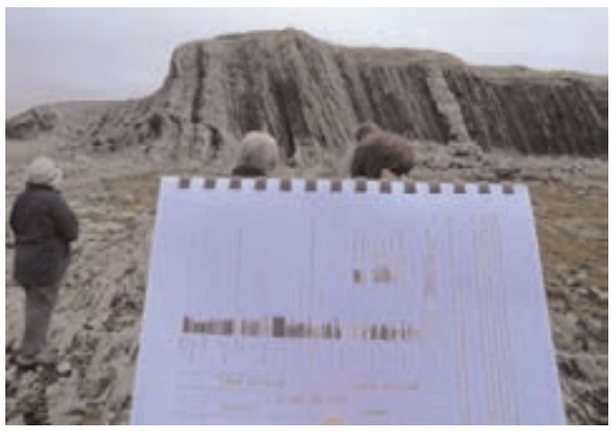

Figure 17 The Cambrian-Ordovician boundary Global Stratotype Section at Green Point (LF).

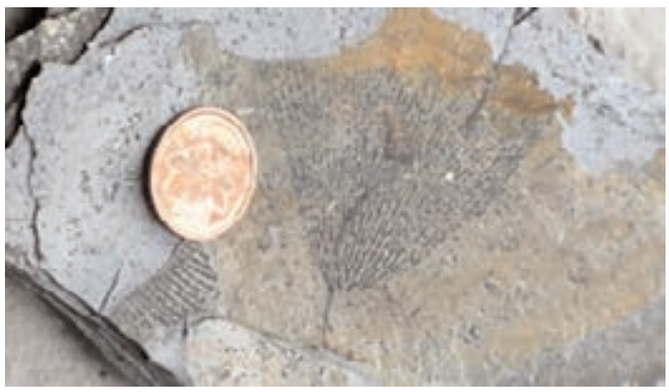

Figure 18 Rhabdinopora*, a planktonic graptolite from Green Point, which was found* c. *4.5m above the Cambrian-Ordovician boundary. This marks the first appearance of planktonic graptolites (SB).*

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In the afternoon, we headed for Western Brook Pond, actually a fjord that has been cut by a glacier, then isolated from the ocean by isostatic rebound. The water is very pure because of the resistant rock, a small drainage basin, sparse plant cover, limited human influence and neutral pH. High cliffs shade the water, keeping it cool and plants are unable to root on the steep sides, circumstances that have led to ultra-oligotrophic water, which inhibits growth of plants and animals.

After a 3km hike on trail and boardwalk over the bog and ridges of the uplifted offshore area we took a boat to the far end of the pond — the head of the fjord — although low cloud obscured the towering cliffs around us. On our return, however, the clouds lifted (Fig. 19). The boat skipper spotted a black bear on the hillside and we spent about 15–20 minutes watching her and her three cubs; the most cubs seen previously by the crew were two so we were very lucky.

Figure 19 Western Brook Pond — a bit of atmosphere as the clouds began to lift (LF).

Towards the end of the boat trip we saw gneisses and igneous rocks dating from *c.* 1,000Ma, forming the southern cliffs; these were intruded by dolerite dykes recording the early stages of the opening of the Iapetus Ocean (Fig. 20). The low cloud and mist rising from the water gave a beautiful atmospheric effect.

The raised seabed between the hills and the coast has bogs in the hollows, with many rare plants and tuckamore, the low, dense growth of stunted, windblown boreal forest on the ridges. On our walk back through this area we saw woodpeckers, evidence of beaver (gnawed tree stumps) and a recently injured hare seeking shelter in the undergrowth.

11th June: A day off *(NF)*

One group's account of their free day.

Deciding to stay local, we drove to Cow Head harbour and walked onto the peninsula along the small Lighthouse Trail. Soon after entering the wooded area we heard a bird of prey, and through binoculars saw a Sharp-shinned Hawk. Birds were all around and one was particularly apparent: the White-throated Sparrow with its distinctive call.

The walk took us through wooded areas and meadows where butterflies were starting to show themselves. We saw a small lilac butterfly and a Monarch butterfly, similar to the British Admiral or Peacock butterfly.

Figure 20 A mafic dyke: evidence of the Iapetus opening, which cuts through the gneiss of the Grenville continental crust c. *1000Ma (LF).*

The lighthouse is quite small and is dwarfed by the trees. As we neared the top of the peninsula there were exposures of limestone conglomerate, which we stood on to see great views of Shallow Bay, its harbour, and the hills of the Gros Morne National Park, which were, for once, crystal clear.

In the afternoon we visited Norris Point on the Bonne Bay peninsula. Again, great photo opportunities from viewpoints around the bay and bird sightings, such as the American Pipit. On the drive back we stopped at the wreck of S. S. Ethie, the steamer that ran aground in 1919 with no loss of hands. All that is left now is a rusting hull and pieces strewn on the beach — there will undoubtedly be less to see in years to come. As we neared the hotel we had to stop the car suddenly as a moose wandered across the highway in front of us! He looked quite young, and just stood there staring at us … so I finally got my moose picture (Fig. 21)!

Figure 21 'Mickey' Moose (NF).

12 June: Thrombolites and polar bears *(BJ)*

Two days on the Great Northern Peninsula followed, moving from transported, allochthonous rock slices onto the Laurentian shelf autochthon as we drove north along the west coast, alongside the Proterozoic basement rocks of the Long Range Mountains finally reaching St Anthony. The tip of the Great Northern Peninsula is a complicated assemblage of thrust slices, which were transported over the Middle Ordovician Limestones of the Laurentian shelf. Six slices have been recognised, the highest and most deformed slices having come from the farthest east.

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Figure 22 The Arches: an eroded sea stack of Ordovician conglomerate (LF).

Heading north, our first stop was The Arches Provincial Park [8.1], where a boardwalk and steps lead down to a splendid beach and three very impressive natural rock arches eroded in a sea stack (Fig. 22). The Arches are composed of the same Ordovician limestone conglomerate first encountered at Green Point, and the beautifully coloured and patterned beach pebbles and boulders here are granites and gneisses brought in by glaciation from the adjacent Long Range Mountains to the east. At least two raised beaches are evident here.

At our second stop [8.2] we examined some familiar fossil rock structures and also reflected on the lives of former generations of Newfoundlanders. The fossils (in a road cut) are stromatolites in Ordovician limestones. Some of the structures are finely laminated and wavy; others have a more mounded appearance.

Across the highway on the seaward side a wooded trail leads down to the peaceful inlet of Deep Cove, flanked by extensive meadows. Within and around these meadows are the ruined remains of wooden dwellings known as 'tilts'. They would have been occupied in the winter by fishing communities, when the occupants would hunt, trap and cut timber. When the ice melted in spring they would move the short distance back to their coastal homes and spend the summer fishing. Seasonal transhumance such as this was unusual among European settlers in North America, but was practised here into the middle of the 20th century.

None of us could have anticipated the bizarre nature of the next location. On the foreshore at Flowers Cove [8.3] it is possible to walk among and between not rock cakes but rather rock buns! These are huge, weathered-out, mound-like structures called thrombolites (meaning 'clotted structure') (Fig. 23). They are of Cambrian age and, like stromatolites, are formed by millions of algae and bacteria. They differ from stromatolites, however, in not growing in layers or laminations. At *c.* 1m high and 2m to 3m in diameter they sit proud on the surface of a horizontal, rippled mudstone, which has been flexed slightly downwards beneath them by their weight. They are said to be analogous to those structures living and growing today in Shark Bay, Western Australia.

Figure 23 Thrombolites at Flowers Cove, with our hardy group picnicking on the exposure (LF)!

A little farther north-east, at Green Island Brook, we looked at another extensive beach exposure of mid-Cambrian limestone [8.4], forming shelves dipping gently to the west and ending abruptly at the sea in very low cliffs. The shelves are covered with frost-shattered rock, traces of burrows are much in evidence and some brachiopods have been found. We learned that the limestone in this part of the Great Northern Peninsula can be closely correlated with the Durness Limestone of Scotland. At this point Tom informed us that although only at the same latitude as Bristol (51°N) we were now officially in a sub-Arctic climate zone and many took a renewed interest in the surrounding wild flowers, particularly Mountain Avens.

We next headed away from the coast, east across the peninsula taking in the bleak but impressive limestone landscape, which in these parts is called 'the barrens' due to the lack of vegetation, especially trees.

On arrival at St Anthony we trooped into the Municipal Building to view a stuffed polar bear, an unlucky one of a number that cross over from Labrador when the sea in the Strait freezes each winter (Fig. 24).

Our final location of the day was Fishing Point [8.5]. From this high vantage point, on a clear day one can see the many icebergs that make a majestic southerly progress down 'Iceberg Alley'; also whales and other cetaceans, but today was not a clear day. Nevertheless most of us descended, through lashing rain, several hundred wooden steps to the beach; on the way we saw some splendid examples of late Proterozoic-Cambrian gabbros ,which form one of the six recognised thrust slices that make up the major part of the peninsula in this locality.

Figure 24 Tom tells us about the polar bear in St Anthony Municipal Building: a number cross the straits from Labrador on pack ice each year (LF).

13 June: Vikings and trilobites *(GD)*

The northern tip of the island is known not only for the complicated geometries of its six thrust sheets but also for its Viking archaeology. After exploring both, we headed south and saw Cambrian archaeocyathid reefs and trilobites like those in the NW highlands of Scotland – more evidence of pre-Atlantic proximity.

After breakfast we set off to revisit Fishing Point, the headland at St Anthony [8.5] for a brief view stop: an impressive view of the rocky coastline. Then we headed north towards L'Anse aux Meadows [9.1]. At the Interpretation Centre where we were shown a short film about the discovery of the site before being taken on a guided tour.

L'Anse aux Meadows is the site of the first known European settlement on the North American continent. It dates back 1,000 years and has become a UNESCO World Heritage Site

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(www.pc.gc.ca/lhn-nhs/nl/meadows/index_e.asp). The archaeological site was found by a husband and wife team, Helge Ingstad and Anne Stine, in the 1960s, who reasoned from the Norse sagas that Norse explorers must have attempted to settle on the northern coasts of North America and that there must be evidence of this somewhere. They used information gleaned from the Icelandic sagas and the knowledge of the local people to help discover the site. During excavations the foundations of eight dwellings were uncovered, together with contemporaneous iron artefacts. Radiocarbon dates placed the site between 920 and 1020 AD. Iron technology not having been developed in North America at this time provided evidence for a European settlement and other artefacts verified the settlement as Viking in origin.

The site includes a reconstructed long sod house, a full-scale replica of a Viking longhouse, and occupied by several home-grown Vikings to answer questions and tell you more about the building and lifestyle of those who lived in such houses a thousand year ago. The recreation could so easily have been kitsch, but instead it came across as informative, interesting and tastefully done (Fig. 25).

Figure 25 L'Anse aux Meadows — a non-kitsch home-grown Viking answers our questions (LF).

With the wind rising and rain starting to fall, we stopped for lunch at the Tickle Inn, a small Bed and Breakfast establishment described as 'at the end of the Viking Trail' and 'the most northerly home on the island of Newfoundland' (Fig. 26). The restored house dates back to the 1890s and care had been taken to retain the original style of furnishings and decoration. We were both grateful for the hospitality to shown to us as well as for the opportunity of seeing inside a Newfoundland home (www.tickleinn.net/). After lunch we set out to walk to Cape Onion, the rocky headland behind the Tickle Inn. By now the wind had risen further and with Tom leading we made our way to what could be described as a windy knoll. Several icebergs could be seen in the distance, their 10,000-year-old ice cores slowly melting into the stormy sea (Fig. 27).

The cliffs at Cape Onion [9.3] expose a mélange of mudstones, part of a thrust slice formed during ocean closure. Basaltic pillow lavas are evidence of underwater volcanic activity associated with the thrust. These were little deformed or altered but, above all, they were accessible on the beach, although the weather continued to encourage us back to the cars. Retracing our route of two days earlier back to Port au Choix our view west across the

Figure 26 The Tickle Inn at Cape Onion (LF).

Figure 27 Stormy seas off Cape Onion (GD).

sea to the Canadian mainland were less hampered by low cloud and fog, and we were afforded a good view of the Labrador coast only a few kilometres away across the Strait of Belle Isle.

Our final stop took us to the disused Mount St Margaret Quarry [9.7)]. Here thinly-bedded shales with occasional thin sandstone beds formed a cliff face *c.* 10–12m high. The fossiliferous Lower Cambrian mudstones contained archaeocyathids, an extinct reef-forming organism (Fig. 28). Archaeocyathids were distantly related to corals and sponges and inhabited shallow marine waters. Their cone-shaped bodies were frequently found in the more compact sandstones and some blocks were found packed with the fossil creatures.

Figure 28 Archaeocyathids at Mount St Margaret Quarry (LF).

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However, our main aim in the quarry was to identify the trilobite *Olenellus* (Fig. 29), a creature that can also be found in the Scottish Highlands. It provided key evidence that Scotland and Newfoundland were part of the same Laurentian continent during Cambrian times, before they were separated by the opening of the Atlantic Ocean. The friable shales yielded various fossils along the thinly cleaved bedding planes. We found many examples of trace fossils, gastropods and brachiopods, and occasional pieces of the exoskeleton of trilobites, including, we hoped, *Olenellus*. After a concerted effort enough fragments of *Olenellus* were found for Tom to be satisfied that we had achieved our goal.

Figure 29 Olenellus *from the Humber zone in western Newfoundland (LF).*

14 June: Indians and Eskimos *(GT)*

The Port au Choix area has been continuously settled for the last 5,500 years and provides evidence of interaction between people, climate and sea level change: the Maritime Archaic Indians were descendents of the first people to cross the Bering Strait into North America. They occupied this area 9,000–3,000 years ago. Groswater Palaeoeskimos were descendents of Siberian hunters: they reached Alaska c. *5,000 – 4,000 years ago and moved eastward, reaching this area 2,800 years ago. They were succeeded around 1,900 years ago by the Dorset Palaeoeskimos and then by Recent Indians from interior Quebec and the Labrador coast. Port au Choix became a French fishery in the 18th and 19th centuries and was permanently settled by English immigrants from the early 19th century.*

We spent the morning in the Port au Choix area combining geology with archaeology, as the area provides evidence for a long period of continuous occupation in North America: some 5,500 years. The Maritime Archaic Indians — descendents of the earliest migrants into North America across the frozen Bering Strait *c.* 12,500 years ago — inhabited the coastal region from Labrador to Maine between *c.* 7,000 and *c.* 3,000 years ago. After them, Groswater Palaeoeskimos were the first arctic-adapted people to arrive in Newfoundland, migrating from the Canadian Arctic and Greenland via Labrador, and inhabiting the island from *c.* 2800 to *c.* 1900 years ago. Dorset Palaeoeskimos were a second arctic-adapted people to migrate into Newfoundland, overlapping with the Groswater between *c.* 2100 and *c.* 1900 years ago. From *c.* 2,000 years ago prehistoric Amerindians known as the Beothuks lived in Newfoundland and Labrador, surviving into the historic period.

The town is situated on a narrow isthmus that connects the Port au Choix and Point Riche peninsulas to the mainland. The former is underlain by Lower Ordovician dolomitic limestone of the Saint George Group, while the latter is underlain by Middle Ordovician limestones of the Table Head Formation. Post-glacial climate and sea-level changes over the past 12,000 years caused the land to rebound, creating first islands and then the peninsulas.

The three groups of ancient peoples who occupied the area successively were hunter-gatherers who hunted for fish, seals, birds and caribou using blades of shaped slate, and of knapped quartz and chert. The discovery of a Maritime Archaic Indian cemetery in Port au Choix town [10.1], situated on a raised beach *c.* 6–8 m above sea-level, and knowledge of climate and sea-level changes led to identification of other sites and a greater understanding of these early settlers. About 3,200 years ago, as the climate cooled, these people were replaced by Palaeoeskimos: the Groswater who used chert from Cow Head to fashion spearheads and built seasonal camps and by people of the Dorset culture, who built more permanent settlements, as well as seasonal camps. The Dorset people carved soapstone bowls from a quarry on the Baie Verte Peninsula to the east and left the area by 1300 AD as the climate warmed, affecting the extent of sea ice and seal hunting. The National Historic Site Visitor Centre [10.3] is well worth a visit to view artefacts retrieved from local excavations (www.pc.gc.ca/lhn-nhs/nl/portauchoix/visit/index_e/asp).

Walking a trail from the Centre to the north shore of the Point Riche Peninsula took us over a barren area of limestone gravel. Off path are areas of fragments that have been sorted into stripes or circles by freezing and thawing of the subsoil under periglacial conditions (Figs 30 and 31 *both overleaf*). As the path climbed to the highest point of the peninsula, the vegetation changed from low-lying shrubs to mature trees – evidence that the hill top had emerged earliest during isostatic rebound. Further evidence is that pebbles in the periglacial circular patterns at the top of the hill are more rounded, owing to longer exposure to rain, than lower down the hill.

Limestone bluffs near the summit are old sea cliffs and contain caves in which Dorset Palaeoeskimo graves have been found. The walk brought us to Phillips Garden [10.4], a meadow comprising two raised beaches, *c.* 8–11m above sea level, on which the foundations of at least 50 Dorset Palaeoeskimo houses have been found — the hollows that formed the base of the houses are clearly visible, as are the ridge that separates the beaches.

At Point Riche Lighthouse [10.2] we looked for fossils in the gently folded limestone and shale beds of the Table Head Formation (no collecting). Fossils found included gastropods, bivalves and trilobites, evidence for shallow water conditions at the time of formation.

From Port au Choix we drove south back through Gros Morne National Park to Deer Lake, stopping *en route* at Cow Head [7.3] to look at the chert band used by the palaeoeskimos to fashion tools and weapons. The chert is found within Cambrian-Ordovician shales, limestones and limestone conglomerates of the Cow Head Group. The conglomerates were deposited in deep water of the Iapetus Ocean when earthquakes triggered submarine landslides on the Laurentian continental slope, with some of the clasts measuring up to 200m across.

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Figures 30 and 31 Patterned ground: stone rows (above) and circles (below) — limestone barrens, Pointe Riche Peninsula (LF).

15 June: Soapstone and serpentinite *(NF)*

After a night at Deer Lake (including the obligatory meal at Jungle Jim's, amidst fake foliage and plastic snakes) we explored the Baie Verte Peninsula, mainly along the Baie Verte Line (analogous to the Highland Boundary Fault) that separates the North American Humber Zone to the west from the deep sea floor sediments and volcanic rocks of the Dunnage Zone to the east. Cambrian and Ordovician ophiolite slices have been caught up along the length of this line: the origins of the soapstone, asbestos and altered ultramafic rocks that we were able to examine before heading on to an overnight stop at Gander.

Our first stop was the Dorset Palaeoeskimo soapstone quarry at the northern end of Fleur de Lys [11.2]. Soapstone is a very soft, altered ultramafic rock, probably related to the ophiolites of the Baie Verte Line. Unfortunately, the visitor centre was closed but we took a short walk to the face of the quarry where the Dorset people had worked the quarry face to carve out rounded blocks of soapstone to make into bowls and lamps, *c.* 1,500 to 1,600 years ago leaving the quarry face scarred with many small, square pits (Fig. 32). The stone was worked using tabular scrapers of hard sandstone, and by stone chisels and picks. Vessels made of soapstone from here have been found at other Dorset sites, such as Cape Ray and Port au Choix.

At a quick visit to a road-cut we had passed earlier we saw altered ultramafic rocks again — serpentinite.

Next we stopped at a viewing platform to look into the disused Advocate Asbestos mine [11.1]. Unfortunately rain and fog obscured the view into the deep opencast mine, but a short drive along the highway brought us to a spoil heap. Here lovely samples of serpentinite and some chrysotile (a fibrous silicate mineral formed of asbestos, could be found. Hot fluids flowed through the fractures of the ultramafic rocks of the Advocate Complex to form chrysotile and serpentinite. The mine ceased extraction in the early 1980s after reduced demand, because of increasing health concerns, led to its closure. Another stop at a road-cut enabled us to obtain the best samples yet of serpentinite. Some was encased in its host rock, while other samples were pure crystals — fibrous and flaky in some cases and beautiful, translucent, pale- to mid-green.

Our final stop was another roadside exposure at the northern end of Flatwater Pond [11.4], of Advocate Ophiolite Complex rocks. These are ultramafic rocks that have been extensively altered to serpentinite and another rock known locally as virginite (Fig. 33). The latter is bright, pale green when fresh but weathers to a rusty brown. It comprises mainly breunnite, a pale green variety of magnesite (magnesium carbonate), which contains up to 30% iron carbonate. Also present are small amounts of fuchsite, polydymite (nickel sulphide) and quartz. The virginite is enclosed by a zone of carbonate-serpentine-talc rock gradually passing into serpentinite. It is thought to have formed when carbon dioxide migrated into the serpentinite along the fault system of the Baie Verte line. Why virginite you may ask? Well, 'it's rare, it's green and it's hard to break!' I believe that is the local saying.

Figure 32 Fleur de Lys soapstone quarry, Baie Verte Peninsula: the individual 'bowl holes' are c. *200–300mm across (LF).*

Figure 33 Virginite exposure on the Baie Verte Line: the mineral is a vivid green, weathering to brown; the exposure is crossed by quartz veins (NF).

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16 June: Return to Avalonia *(NF)*

The relatively short morning's drive from Gander back to St John's gave us an opportunity to examine one of the significant exposures on Conception Bay that had been omitted on the outward journey. At Harbour Main (3.2) we were able to see glacially smoothed shoreline rocks of the Gaskiers Formation. Part of the Conception Group, these rocks have a green, purple and red matrix, which supports pebbles and cobbles of volcanic rocks, granite, quartzite, siltstone, chert and limestone. Most clasts are rounded, but some are angular. This is a diamictite (sometimes known as a mixtite) derived from glacial material deposited at the end of the Gaskiers phase at the end of the Marinoan glaciation and dated 595Ma (Fig. 34). This was the glaciation that immediately preceded the emergence of the Ediacaran biota. The diamictite is overlain by a red mudstone, indicating increased post-glacial oxygenation and it is topped off with a cap carbonate (although we did not see that).

Figure 34 Diamictite, Gaskiers Formation, Harbour Main (LF).

On the drive back to St John's from Gander Lake we travelled over schists and gneisses of the Gander Zone and, near Gloverton, crossed the Dover Fault into the Avalon Zone. Through the Terra Nova National Park and across the Isthmus of Avalon we travelled on Late Proterozoic sedimentary and volcanic rocks. From then on it was over the Trinity Bay synclinorium, with Cambrian sedimentary rocks at its core. Then came a cover of till, sand and gravel in the form of Rogen moraines deposited by a glacier moving north-eastwards. As we neared St John's the rocks are folded into a series of north–south striking anticlines and synclines within the Trinity Bay synclinorium and the Conception Bay anticlinorium. The Topsail Fault was crossed and from there to St John's the rocks are Late Proterozoic sediments of the Conception Group.

Back in St John's we congregated at the new museum/art centre called The Rooms (www.therooms.ca). Inside there is a mixture of natural history, art, photography and archaeology. The natural history section helped identify many of the birds, flowers and animals that we had seen over the two weeks.

17 June: Farewell to St John's *(NF)*

Although the main group went down to Witless Bay to go whale watching, some chose to explore St John's and a group headed a short way south to Petty Harbour, just beyond Cape Spear. Here we were able to combine sightseeing with geology, as this area is where the younger rocks in the core of the Blackhead syncline crop out (the western and eastern, older limbs crop out on the Southside Hills by St John's Harbour and at Cape Spear). At Petty Harbour [1.4], a pretty fishing port dating back to the 16th century, we found resistant sandstones and conglomerates of the Petty Harbour Member of the Blackhead Formation forming the headland north of the bay. The bay itself is eroded along the strike of softer mudstones and although the quaint fishing sheds lining the shore have featured in a number of films the village is remarkably unspoilt (Fig. 35).

Figure 35 Petty Harbour: picturesque traditional fishing sheds on the waterfront make this a favoured location for filming. The penstock for the island's first hydro-electric power station is on the right (LF).

A morning of relaxation: some of us went souvenir shopping in St John's. We visited Devon House Craft Centre, which is the showcase for the best craft workers in the Province: selling soapstone art and sculptures, labradorite jewellery, locally made soaps and Inuit art.

The afternoon was for the boat trip from Witless Bay, hoping to see icebergs, puffins and whales. We were not disappointed! There were two big bergs in the bay — the smaller had calved from the larger about two weeks earlier according to the guide. The boat went close enough to scoop-out bits of the ice, which appeared incredibly blue in the sunshine, with rivulets of melt water running down the sides (Fig. 36).

Figure 36 Iceberg with melt water runnels down the side (NF).

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After viewing the icebergs the boat took us to the nearest island in the bay to see the Atlantic Puffins, diving off the bow of the boat and then running along the surface of the water as they tried to get into the air to escape the boat: beautiful birds. There were also Guillemots, Kittiwakes, Common Murres, Razorbills, seagulls and Arctic Terns all flying overhead.

Then it was out into the deeper water, beyond the bay, to look out for whales. The captain had a rule that the first person to see a whale got a shot of 'screech' (locally made rum) — The lucky person turned out to be our leader Tom. The whale calf was seen first, closely followed by its mother. They were humpbacks, and she even showed her tail fluke at one point (Fig. 37)! I felt very honoured to have seen them … on our last day too.

Figure 37 The fluke that earned Tom a shot of 'screech' (JH)!

Additional images of locations visited are at
http://picasaweb.google.co.uk/Lindamaryfowler/NewfoundlandShoestring2008?authkey=yy_irkGXL_0
and can be viewed in Google maps or in the interactive Google Earth program if you have it installed. (LF)

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Book review

George, Gareth T. 2008 *The Geology of South Wales – a field Guide*. garethtgeorge@geoserve.co.uk (ISBN: 978 0 95593 710 1; paperback, 247pp; £17.99 (available at a discount for OUGS members through Leslie Laws, OUGS Sales Officer)

Gareth George is a retired academic who has been a teacher, part-time OU tutor and consultant to the oil industry. He has run many field trips to South Wales for undergraduates, postgraduates and oil company personnel. He started his geological interest at Swansea University.

On the back jacket is an overview of the book and its aim:

"The Geology of South Wales provides up-to-date field itineraries to five regions noted for their beautiful scenery and outstanding Geology.

The itineraries are well-illustrated with line figures (120), including location and geology maps, cross-sections, stratigraphic columns, graphic logs and depositional facies models, black and white (56) and colour (21) photographs.

The field-guide is user-friendly and suitable for a range of Earth scientists; enthusiastic amateurs, schoolteachers, undergraduates, Open University students and professionals. Most of the main disciplines of the Earth sciences are covered, including stratigraphy, sedimentology, palaeontology, structural and igneous geology, and geomorphology.

The extremely important concepts, principles and applications of the relatively new discipline of sequence stratigraphy are introduced and explained by reference to many excellent field examples and case studies of Upper Carboniferous strata. Key stratigraphic surfaces, present within these sequences, record significant changes in relative sea-level, which were driven by both glacio-eustatic and basinal processes."

This book would be useful for anyone attending next year's Swansea Symposium and wanting to explore the region.

An experienced field study leader, Gareth has used his own photographs and visited all the sites since 2005. It is written with humour, very easy to read and suitable for use by groups or individuals. The maps, field sketches and photographs all aid the identification of precise localities, structures and specimens.

Chapter one provides a comprehensive introduction to the region, with sections on transport, accommodation, landscape, scenery, prehistory, historic sites, cultural attractions, exploring on foot, wildlife, and sport and leisure activities.

Chapter two gives an overview of the region's geology through its structural and stratigraphic framework and concludes with a comprehensive safety and equipment reminder for individuals and groups. There is also reference to the most useful appendices.

The areas covered are:

chapter 3 Vale of Glamorgan (six itineraries)
chapter 4 Gower (4)
chapter 5 Headwaters of the River Neath and River Tawe (3) – this chapter includes two sections on sequence stratigraphy
chapter 6 South Pembrokeshire and Carmarthen Bay (16)
chapter 7 North Pembrokeshire and Cardigan Bay (9)

This most useful book concludes with a comprehensive glossary and bibliography.

It is a similar size to the BGS regional guide and comes with a waterproof cover. I should like to take it with me on any personal expeditions to South Wales, for I feel that it would enable me to see and understand so much more about the region.

— M. Rosemary Darby, BA (Open); BSc Hons (Open) Natural sciences with Earth Science; Certs Ed.; OUGS

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A critical evaluation of how evolutionary theory has changed since Darwin

Kevin Brown

In this 'year of Darwin' it seems almost compulsory to publish something about the man and his work. Durham University Geology graduate and OUGS Member Kevin Brown has written a useful essay summarising developments on Darwin's work on evolution by natural selection and thoughts by leading evolutionists to refine it as scientific knowledge has increased. Kevin's essay was first publishewd in the OUGS Oxford Branch Newsletter*, and when I read it I suggested to him that he consider submitting it for publication in the* OUGS Journal. *Happily, he agreed. It provides a useful summary for all of us. — Editor*

When Charles Darwin published his book On the Origin of Species by Natural Selection in 1859 his argument had four basic premises:

1. More individuals are produced than can survive.
2. There is a struggle for existence, because of the disparity between the number of individuals produced in reproduction and the number that can survive.
3. Individuals show variation. No two individuals are exactly the same. Those with advantageous features have a greater chance of survival in this struggle for natural selection.
4. As selected varieties will tend to produce offspring similar to themselves, these varieties will become more abundant in subsequent generations. This is what Darwin called the principle of inheritance (Skelton 1993, 3)

Darwin proposed that biological evolution took place owing to the occurrence of natural selection and was the first theory that relied on natural causes; previous theories had relied on supernatural or divine causes (Skelton 1993).

By combining all the evidence Darwin proposed that all organisms had descended from a common ancestor. This is not disputed in the scientific community today; however, the mechanism of evolution is still debated.

Darwin defined evolution as descent with modification. Most organisms reproduce sexually, which creates differences between parents and offspring and results in modification in the descendent generations.

Although Darwin's theory of evolution still forms the basis of modern evolutionary theory today, scientific knowledge about variations in organisms has become far better understood owing to developments in genetics, molecular biology, biochemistry and DNA research, which have led to an understanding of mutation and heredity. None of these new scientific disciplines were available to Darwin, and the weakness of his theory was that he could not explain the actual mechanism of evolution. He proposed that variations in organisms arose through natural selection, and that if they were advantageous and in the right environment, then the organism would go on to produce more offspring.

Neo-Darwinism (sometimes called the modern synthesis) is the synthesis of Darwinian natural selection and Mendelian genetics. Gregor Mendel had studied the heredity of garden peas in the 1850s, although his work went unrecognized during his lifetime he had discovered dominant and recessive alleles. However, it was not until 1900, 15 years after Mendals death, that his work was recognized by the new science of genetics.

Darwin assumed that natural selection occurred gradually, that species changed because tiny variations occurred over many generations. This view was opposed by the early geneticists, but by 1920 it was realized that natural selection could act on genes. Geneticists continued to experiment, and also developed mathematical models of evolution. This new approach — known as population genetics — led to the understanding of mutations and how they could spread through a population. Population genetics became the key part of the modern synthesis. Darwin had no explanation for heredity but the new geneticists made a distinction between the genotype (a set of genes possessed by an organism) and phenotype (physical and behavioral traits that are the result of interactions with the environment). In the neo-Darwinian theory information passes only one way, from the genotype to the phenotype, and hence mutations are random and can go only one way. Darwin's view, first proposed by Jean Baptist Lamarck (1744–1829), was that organisms could pass on traits and characteristics they had acquired during there own lifetime (Oxford 2008).

Following the discovery of DNA in the 1950s by Watson and Crick the pace of evolutionary research intensified. Before the 1970s DNA proteins were used to study evolution, but as techniques improved over the next decade it became possible to sequence the DNA of entire genes (Berkeley 2008). DNA is a very simple mechanism, which replicates the molecule and also carries the base sequences as coded messages. The Mendelian theory viewed genes as single units controlling single characters, while the modern synthesis states that genes are segments of DNA molecules that specify proteins, and hence characters. Information can be passed from the DNA to the cell, but not from the cell to the DNA, meaning that characters acquired during the life of the organism cannot be inherited (Patterson 1999).

Darwin's uniformitarian approach consisted of three tenants: agency, efficacy and scope. Agency is the level of the unit on which natural selection acts; for Darwin this is the organism. Gould (2002) takes the view that natural selection works on many levels. Dawkins (1976) developed the 'selfish gene' theory, hypothesizing that natural selection, and hence evolution, acts on genes alone. The genes that are passed on are acting only in their 'own interest' and not in the interest of the organism, hence the term 'selfish gene'. Dawkins describes how genes group together inside a genome, and calls these 'vehicles' that promote mutual interest, enabling the vehicle (genome) to jump into the next generation and so promote there own propagation.

'Efficacy' is the term Darwin used to define how natural selection is the mechanism by which evolution occurs. Efficacy is a creative force of evolutionary change, it can be positive — creating fitness; or negative — eliminating the unfit.

'Scope' as defined by Darwin is the idea that natural selection is responsible for all the major and minor life patterns on earth. Darwin argued that scope generates all the divergent life-forms known today by 'incremental accretion of tiny contrasts' from one common ancestor. Scope is an extrapolation from micro- to

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macro-evolution, which enabled Darwin to explain biological diversity and evolution of the higher taxonomic groups.

Adaptation is a process that operates over many generations, on structures that are fitted to a particular function, Darwin used the term fitness to mean 'better adapted'. Fitter organisms are better adapted to their environment, which therefore promotes survival and reproduction. Sexual reproduction promotes variation in organisms; if the adaptive features are inherited and promote fitness, then the next generation has a better chance of survival; however, if the inherited features do not promote fitness, then this reduces the chance of survival.

Evolutionary theory and developmental biology ('evo-devo') only came together over the past two decades (Kutschera 2004) in order to explore the evolution of developmental processes and how the different body plans of past and present organisms arose. The synthesis of evo-devo led to the discovery of regulatory genes called 'Hox genes'. These genes encode the DNA binding proteins that influence embryonic development. According to Galliot (2004), Hox genes encode positional information during development. The physical location of the Hox gene is located along the anterior to posterior of the organism in a position relative to where it will form limbs, eyes, toes and other body parts and organs. Hence it is the Hox genes that form a body plan during the early stages of development.

When Darwin introduced the concept of 'gradualism' in 1859 he meant that the higher taxa and body plans were the result of the accumulation of small changes in evolution over time. Kutschera (2004) quotes Mayr in the middle decades of the last century (see Mayr 1942) as determining that the origins of the higher taxa are simply an extrapolation of speciation. Kutschera goes on to say that "all evolution is due to the accumulation of small genetic changes guided by natural selection and that evolution is nothing but an extrapolation and magnification of events that take place within populations and species …" (Kutschera 2004; Naturwissenschaften 2004).

Although there is still debate as to what extent macro-evolutionary changes are the effect of micro-evolutionary modifications, Kutschera (2004) goes on to describe how this is documented in the fossil record. Vertebrates include forms that are intermediate between fish and amphibians, between amphibians and reptiles, between reptiles and mammals, and between theropod dinosaurs and birds. Kutschera describes examples of intermediate forms linking these major groups of vertebrates. All specimens were discovered in the last *c.* 25 years and represent links in the fossil record of vertebrates.

Gould and Eldridge (1993) proposed a theory they call 'punctuated equilibrium' as an alternative to Darwinian gradualism. Gould (2002) summarized this theory, saying that "evolution tends to be characterized by long periods of stasis (equilibrium) punctuated by episodes of rapid phenotypic change". The situation so-named by Gould and Eldridge as punctuated equilibrium was described by Darwin as 'imperfection' in the fossil record, which he believed to represent the result of phyletic gradualism. Gould's interpretation is that when phenotypic evolution occurs it is localized to rare and rapid events (rapid in a geological sense), which results in branching speciation (cladogenesis).

In contradiction, Richard Dawkins (1996) has been a strong critic of punctuated equilibrium. He says that phyletic gradualism (a constant change over time) does not exist and so the rate of change over time must be variable. Dawkins interprets Gould as saying that Gould believes "evolution occurs in bursts or not at all". (A fuller discussion of the differences between Dawkins and Gould can be found in Sterelny 2001).

In order to understand evolution it is necessary to understand variation in organisms, as for Darwin the emphasis was put on selection. Mutation of genes, as discussed, is one way in which variation occurs within organisms. Heterochrony is "a genetically determined change in the timing of developmental events relative to the same events in the ancestor" (Skelton 1993, 723–8). Ernst Haeckel first used the term 'heterochrony' in 1875, he was a supporter of Darwinian theory and promoted it in Germany at that time. Heterochrony can work in two directions, if, for example, the descendent reaches adulthood at a later stage than the ancestor then it is known as peramorphosis (over development); if, however, the descendent reaches adulthood at an earlier stage than the ancestor it is known as paedomorphosis (under development).

In a series of books written between 1930 and 1958 de Beer redefined the concept of heterochrony in an attempt to show different kinds of changes to the developmental timing of evolutionary change. De Beer's argued that innovations in evolution occurred at any stage in the life history of an organism and that changes in the timing of any event could occur at any point during ontogeny (Smith 2001). Gould took the subject of heterochrony further in 1997 with his book *Ontogeny and Phylogeny*, saying that heterochrony is the mechanism that produces parallels between ontogeny and phylogeny. De Beer's had argued that there are many kinds of heterochrony, one of which — allometric growth — was central to his thinking. Gould, for his part, focused mainly on rates of relative growth and shifted the emphasis on the central theme of heterochrony from the relative timing of developmental events to changes in size and shape (Smith 2001).

Whether or not micro-evolution can account for macro-evolution, the idea of large-scale changes of form over geological time is still a matter of debate. Macro-evolution involves changes of form and diversity over large time scales, and thus is the study of evolution beyond the species level. Darwin knew species could change over time — artificial breeding of domestic animals had proved this and Darwin had also seen evidence of this in the fossil record. He considered natural selection in nature to be the equivalent of domesticated breeding and concluded that the processes responsible for macro-evolution were the same as those responsible for micro-evolution. Many scientists have questioned this, however, asking how such processes could produce new body plans, organs or species (Bowler 1989).

Ivan Ivanovich Schmalhausen (1884–1963) and Conrad Hal Waddington (1905–1975) were two non-Darwinian evolutionists who argued during the first half of the 20th century that the processes of macro- and micro-evolution were different. They argued that macro-evolution occurs, but that it is restricted by developmental constraints due to changes in population under conditions of stress. Many other scientists did not hold this view, leading to Stephen Jay Gould's proposal of the theory of punctuated equilibrium in the 1970s (as discussed above), which can at least in part explain macro-evolution.

The history of evolutionary theory since Darwin can be viewed in the context of evolution itself. If one assumes Darwin to be the common ancestor, or at least the first eukaryote, then those who theorized before him were prokaryotes. Over the past 150 years evolutionary theory, like evolution itself, has diverged, run parallel and converged, with some branches becoming extinct — e.g.

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Schmalhausen and Waddington. The advancement in genetics by the 1920s led to the 'new synthesis' and to de Beer's redefinition of heterochrony between 1930 and 1958, which was subsequently taken up by Gould in the 1970s and led to an even greater synthesis between the different disciplines studying evolution. The discovery of DNA in the 1950s led to the decoding of entire gene sequences by the 1980s; and, today, to the decoding of the genetic codes of entire organisms.

Evolution works by natural selection and operates at both micro- and macro-evolutionary levels. Constraints can be either internal or external, and evolution must be considered in the context of chance. If there is not an ecospace to occupy, then a species or organism must find a different ecospace or adapt so that it can stay where it is.

In conclusion, Darwin's theory of evolution is still relevant today, it has been modified by science just as neo-Darwinism will be developed by future scientific advances.

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The author

Kevin Brown BSc Hons (Durham)

Book review

Kokelaar, B. K. and Moore, I. D. 2006 *Glencoe Caldera Volcano, Scotland*. Keyworth, Nottingham: British Geological Survey (ISBN 0 85272 525 6; paperback, x + 127pp; £15); with *1:25 000 Map of Glen Coe* (2005), £22; or map sold separately for £12

Glen Coe is such an amazing experience when you only drive through it on the way to Skye that you are not surprised to learn that it is probably the world's most instructively exposed caldera.

The discovery that it was a caldera volcano was made by Clough, Maufe and Bailey of the Geological Survey in 'meticulous' investigations published in 1909, and this [discovery] "profoundly influenced subsequent studies throughout the world, particularly of modern volcanoes where processes at depth could only be inferred indirectly".

Further studies of the Glencoe caldera were made in the 1960s and 1990s, and now a complete resurvey has been made by the authors of this book, which is published with a 1:25 000 map in the BGS 'Classical Areas of British geology' series. Although there are nine other 'classical area' maps now published with accompanying booklets, this is the first one to have a full-scale book with coloured diagrams and photographs. (The 'classical areas' are curiously light on Scotland: half of the 50 areas are in just four regions: the Lake District, the Peak District, south Shropshire, and Snowdonia, with only five in the whole of Scotland — six of you include St. Kilda.)

The book begins with a most useful introduction, giving not only an outline of the geology but also some useful pages on "what a caldera is, and why Glencoe caldera volcano is so important" — chiefly because the "exceptional exposure [resulting in] extremely rugged topography [provides] excellent opportunities to examine the internal volcanic structure at various levels through to the underlying basement". But also the new studies have shown that "the volcano was far more complicated than previously thought, and that it was strongly influenced by the location and activity of underlying faults… Having once been the original piston-subsidence cauldron, it is now perhaps the prime example of a tectonically controlled, piecemeal, multi-subsidence caldera volcano".

Succeeding chapters deal with: previous studies; an overview of the succession and structure; the volcanic history in great detail (52 pages); a consideration of the ring-fault system and fault-intrusions; later related magmatism; controls on the location and evolution of the Complex; the timing of eruptions; and 'shaping the landscape' — the important developments of the last two million years, which give the glen its spectacular appearance and enable the fieldwork — ensuring that any geologists performing it must also be more than adequate mountaineers.

The book is lavishly illustrated, with 28 figures in colour, including maps — all extremely clear — 27 coloured plates and a full-page frontispiece,; also with two tables. The bedrock map has three cross-sections.

BGS has really pulled out all stops for this important publication. There are seven and a half pages of references and a most useful appendix listing 31 key field localities ("all terrain is potentially hazardous... no listed locality is perfectly safe...")

— Philip Clark, MA (Oxon), BSc Hons (Open)

Quaternary events and landforms in Pembrokeshire

John Downes

The Quaternary Period is divided into the Pleistocene and Holocene epochs, each of which may be further divided into terrestrial chronostratigraphic stages relating to glacial and interglacial periods (Fig. 1). However, in recent years, a more detailed succession has been recorded from deep oceanic sediment cores, using isotope studies. These studies suggest that the major warm and cold stages are controlled by variations in solar radiation input, and are controlled by perturbations in the earth's orbit known as Milankovitch cycles.

The Pleistocene began some 2.5Ma ago and lasted until 10,000 years BP, during which time there were repeated cycles of global climatic change marked by glacial episodes when sea level was low, and interglacials when sea level rose in response to global warming. The Holocene represents a temperate climatic stage that so far has lasted for some 10,000 years since the end of the last glaciation of Northern Europe.

The earliest known glaciation of South West Wales occurred at some time before the Ipswichian Stage (128–122,000 BP), possibly starting *c.* 140,000 BP when Irish Sea ice advanced south-eastwards towards Pembrokeshire, overriding the Preseli hills and sweeping over the lowlands of the south coast. Local Welsh ice moving south-west down the Teifi and Tywi valleys would also have contributed to the overall depth of ice cover. Unfortunately, there are very few coherent deposits of till that can be confidently assigned to this early glacial stage, as much of older drift has been removed by later glaciation. However, at West Angle Bay a grey-blue clay containing clasts of igneous rock was examined in an excavation at the base of the Quaternary sequence by Dixon in 1921 and later by Bowen in 1977. This till is overlain by raised beach deposits that are considered to have been deposited during the Ipswchian interglacial stage. Further evidence for the advance of the ice at this time comes from the occurrence of erratic boulders and pebbles that have been carried by the Irish Sea ice sheet from as far afield as North Wales and Southern Scotland. A collection of erratics may be seen in the graveyard of Flimston Chapel [SR924956] on the Castlemartin Peninsula. They were found scattered over the surrounding limestone plateau surface and include a gabbro from St David's Head and a dolerite from the Mynydd Preseli. At Whitesand Bay there are igneous erratic boulders sealed beneath the raised beach,

Figure 1 Quaternary stratigraphy in SW Wales.

CHRONOSTRATIGRAPHIC STAGES	CLIMATIC EVENTS	DRIFT DEPOSITS/LANDFORMS
Flandrian	Temperate phase	Blown sand/alluvium/peat Drowned river valleys, Milford Haven Submerged forest, Marros Sands
10,000 BP		
Late Devensian	Periglacial Irish Sea Glaciation [2]	Upper Head, Abermawr & Druidston Fluvioglacial sand & gravels, Mullock Bridge & Grugiau Cemmaes Irish Sea Till, Abermawr, Poppit Sands & Druidston Gwaun Meltwater Channels
26,000 BP		
Middle Devensian		
60,000 BP		
Early Devensian	Periglacial	Lower Blocky Head Abermawr
122,000 BP		
Ipswichian	Temperate Interglacia	Raised Beach deposits Poppit Sands & Broad Haven [Bosherston]
128,000 BP		
	Irish Sea Glaciation [1]	Erratic pebbles and boulders West Angle Bay Till

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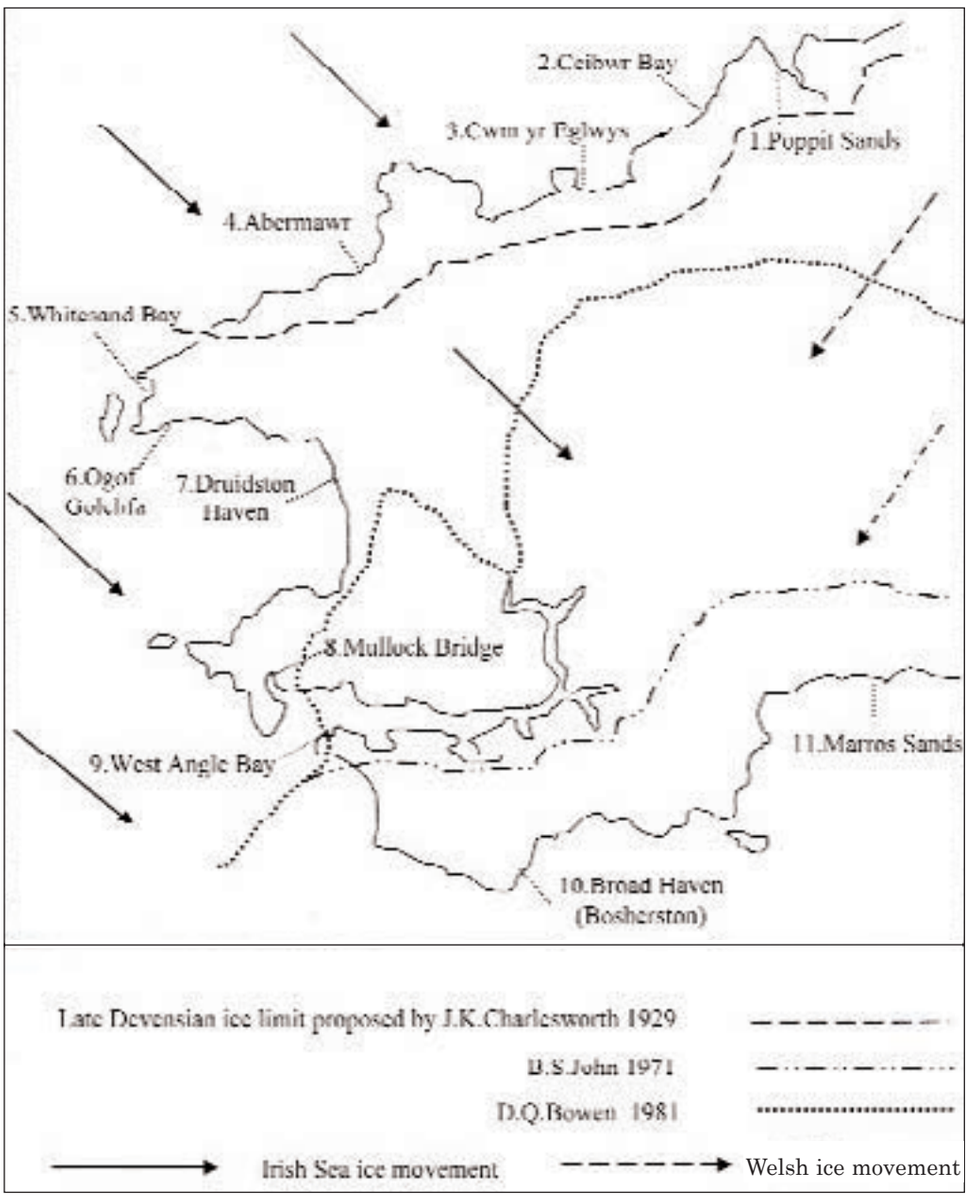
hence, using the Law of Superposition, these erratics must predate the Ipswichian beach deposits and must have been transported during the earlier glaciation.

Sea level may have risen by some 6m during this warmer interglacial stage. The term 'raised beach' implies an isostatic uplift, as is the case on the west coast of Scotland, but in Pembrokeshire the beach platforms are thought to have been produced simply by a eustatic rise in sea level; they could be more appropriately referred to as 'relic beaches'. The best example of a raised beach in Pembrokeshire is seen at Poppit Sands on the Teifi estuary where it rests on an eroded rock platform *c.* 3m above present mean high water. Other raised beach localities include Broad Haven (Bosherston) and Ogof Golchfa (Porth Clais).

At all these localities the cemented beach material is overlain by a deposit of the Lower Blocky Head. This is well developed at Aber Mawr, although no raised beach deposits are present at this site. However, the blocky head consists of unsorted angular rock debris that has been produced by gelifluction, a process involving the downslope movement of the water-saturated regolith under periglacial conditions. This frozen tundra-type environment existed during the Lower Devensian Stage (122,000–60,000 BP) that followed the Ipswichian interglacial.

The next major event in South West Wales appears to be the Late Devensian (26,000–10,000 BP) glaciation, when the area was affected both by the Irish Sea ice sheet and by local Welsh ice streams. The Irish Sea ice front probably did not reach the South Pembrokeshire coast where there is a conspicuous absence of glacial till in the exposed sections. In 1929 Charlesworth proposed a 'South Wales End Moraine' that extended along the North Pembrokeshire coast and it has been argued that the upland landscape around Carn Ingli, 3km south of Newport, shows no sign of being glaciated and so supports the idea that the ice margin generally followed the north coast of the county (Fig. 2). However, other researchers have suggested that the ice sheet reached as far south as the Cleddau estuary (Milford Haven), and in coastal localities such as Poppit Sands, Abermawr, Whitesand Bay and Druidston Haven, the characteristic blue-grey clay Irish Sea till is well exposed. It contains a suite of erratics, with a matrix of calcareous marine silt and clay together with marine mollusc fragments, which suggests that the ice sheet was moving from the north-west across Cardigan Bay south-east towards the Welsh coastline. There is a raised beach platform near the lifeboat station at Parrog in Newport Bay that has been polished and striated by the advancing Irish Sea ice sheet.



During the initial advance of the ice, the existing river drainage systems were disrupted as ice dammed proglacial lakes became established. The most extensive of these was Llyn Teifi, which occupied the estuary of the Afon Teifi and was blocked by the ice front to the west. Borehole logs show that glaciolacustrine silts and varved clays more than 75m thick were deposited within this lake basin. There are also mounds and esker ridges of stratified glaciofluvial sands and gravels that were deposited as meltwater sediment when the ice front receded. These topographical features can now be seen on either side of the Teifi Valley at Trefigin Quarry, Monington [SN139435] and Banc y Warren [SN204475]. Another well-preserved section through a glaciofluvial deposit was exposed in the 1970s in a gravel pit cut into the surface of the kame terrace at Mullock Bridge [SM811080] near Dale. A line of hummocks formed of stratified pebbly sand at Grugiau

Figure 2 Quaternary localities and late Devensian ice sheet movements in Pembrokeshire.

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Cemmaes [SN126415] has been interpreted as an esker deposited in a sinuous channel by a subglacial stream.

The spectacular Gwaun-Jordanston meltwater channel system in the Fishguard area was formerly thought to have been cut by the overflow waters from the proglacial lakes associated with the Irish Sea ice front during the Late Devensian, but it is now considered more likely that the system was eroded by subglacial meltwater flowing beneath and marginal to the ice sheet (Charlesworth 1929). The waters escaped westwards along the Gwaun Valley into Fishguard Bay and southwards through the Scleddau overflow channel (Fig. 3).

Towards the end of the Devensian Stage, periglacial conditions returned to South West Wales with the formation of the Upper Head deposits, which may also include a rubble drift or clay containing various sized boulders of glacial origin.

The last stage in the Quaternary story is dominated by the Flandrian marine transgression of the Holocene period. Although the rate of eustatic sea level rise was greatest during the early Holocene, at that time sea level was considerably lower than at present and it was not until *c.* 6000 BP that the present coastline of the Irish Sea Basin took shape. Submerged forests and peat bogs below MLW bear witness to a former lower sea level (*see below* Locality 11). Eventually the rising sea level caused the drowning of the lower reaches of pre-existing rivers and produced rias, such as are seen at Milford Haven and Solva. Coastal features produced by recent marine erosion include wave-cut platforms, cliff lines, natural arches, stacks, geos (faulted inlets) and caves. These geomorphological phenomena are particularly well developed along the limestone coast of South Pembrokeshire and in the turbidite sandstones of the North Pembrokeshire coast. The Green Bridge of Wales is probably the best known example of a natural arch in South West Wales. Deposition occurs in sheltered bays and estuaries where mud, sand and shingle accumulate to form mud flats, sandy beaches, storm beaches and wind-blown dunes. Broomhill Burrows at Freshwater West provides an excellent example of a wind-blown dune complex. At Newgale on St Bride's Bay, there is a well-developed storm beach formed of shingle, pebbles and cobbles, which have been driven onshore by the prevailing south-westerly winds and longshore drift.

The following Quaternary localities around the Pembrokeshire coast are well worth visiting (*see* Fig. 2).

1. Poppit Sands [SN145490] are located on the SW side of the Teifi estuary c. 3km north of St Dogmaels. The Quaternary sequence at Poppit Sands is exposed for several hundred metres between Cei-bach and Trwyn Careg-ddu, where the steeply dipping turbidite mudstones and sandstones of the Dinas Island Formation (Caradocian Stage) are extensively bevelled to form a rock platform. This feature is *c.* 3m above the present high-water mark and is thought to have been eroded during the Ipswichian interglacial. Cemented pebbles and cobbles, much stained by iron and manganese, form a raised beach resting directly on the bevelled surface (Fig. 4, *opposite*). These sediments are up to 1.7m thick and are considered to be of Ipswichian age on the basis of foraminifera obtained from the cemented beach material. Overlying the raised beach is *c.* 6m of Lower Blocky Head, a periglacial deposit of poorly sorted subangular clasts of local rock. Finally, there is the Irish Sea till, 2m of boulder clay, containing erratics and shell fragments deposited during the Late Devensian glaciation when Irish Sea ice extended across the coastal areas of the North Pembrokeshire coast.

2. Ceibwr Bay [SN108458] lies *c.* 7km SW of Cemaes Head and can be accessed from the village of Molygrove. On the south side of the bay there are several metres of cemented gravel and sands resting on a bedrock platform. The ill-sorted pebbles, angular clasts and cobbles are mainly vein quartz, sandstone and mudstone derived from local bedrock, but there are also some exotic volcanic and granitic fragments. The clasts are partly consolidated by a red iron-rich cement. These drift deposits are thought to have been formed before the Late Devensian glaciation as local regolith, scree and alluvial sediment. The valley that is followed by the road from Moylgrove to Ceibwr Bay is probably a meltwater channel that drained the ice sheet occupying the higher ground to the north.

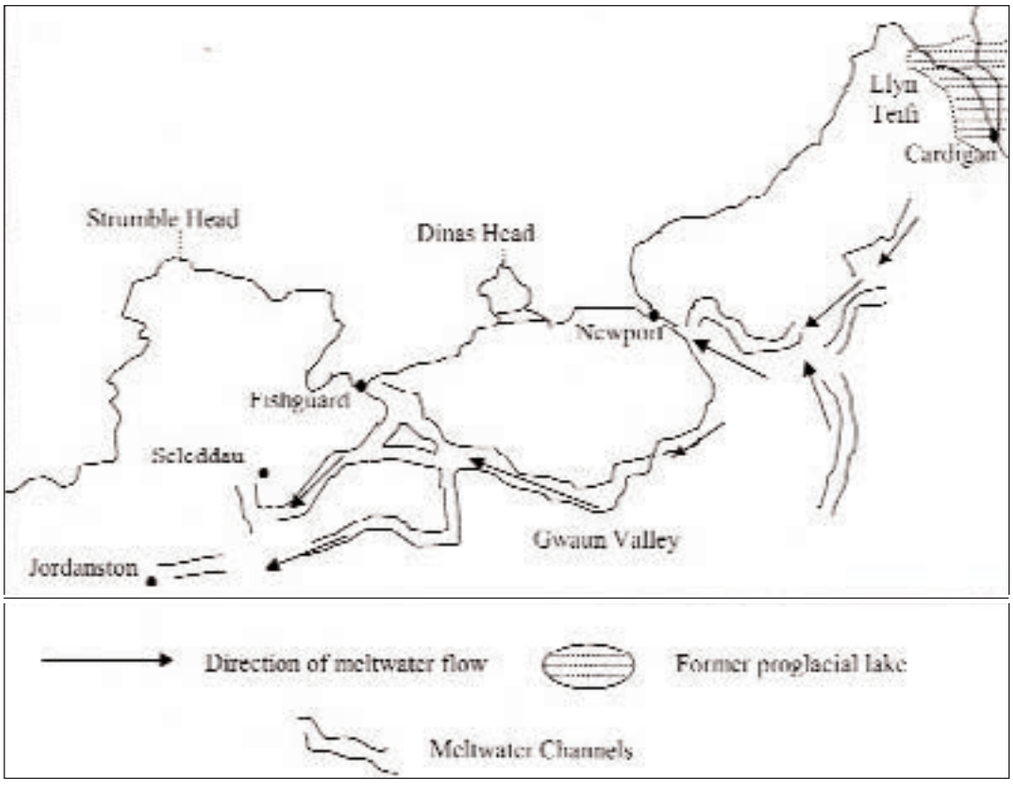

Figure 3 The Gwaun-Jordanston meltwater channel system.

3. Cwm yr Eglwys [SN010399] is situated on the SE corner of Dinas Island. The village can be accessed by a narrow lane from the A487 Fishguard-to-Newport road. From the car park follow the coastal path westwards

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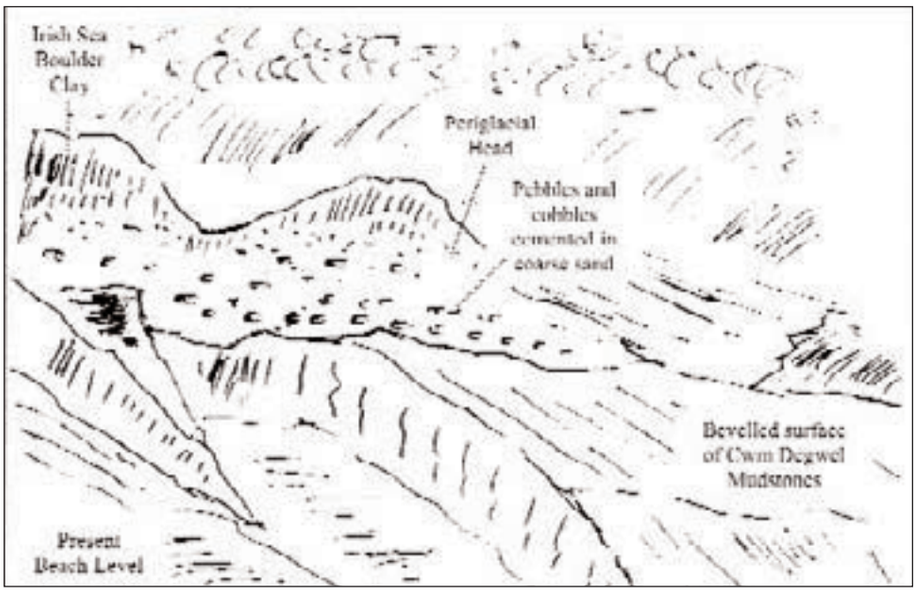

Figure 4 Raised beach at Poppit Sands.

towards Pwllgwaelod through a steep-sided, flat-bottomed marshy valley. This is part of the Gwaun-Jordanston meltwater system cut by sub-glacial streams during the advance of Irish Sea ice across North Pembrokeshire in Late Devensian times (*see* Fig.3). The meltwater channel is floored by Late Devensian sediments deposited by sub-glacial streams. Overlying peat beds have yielded pollen grains that have provided evidence for climatic change since the last ice age.

4. Aber Mawr [SM883346] can be approached from the A487 Fishguard-to-St David's road. Leave the main road near Mathry and follow the narrow lane northwards for 2km, bearing left just beyond Parc-y-nole farm. Park near the lane that takes a sharp bend, next to the National Trust sign at the entrance to Pen-yr-alt Wood [SM885337]. Walk along the woodland path that leads to the south side of Aber Mawr beach. The Quaternary section can be seen above the northern end of the present storm beach, where there is a drift cliff *c.* 13m high (Fig. 5). The latter rests on the eroded surface of the vertically cleaved mudstones of the Ogof Hen Formation (Lower Ordovician, Arenig Stage). The lower part of the drift cliff is composed of Lower Blocky Head with angular erratic blocks and rock fragments, above which there is a wedge up to 2.5m thick, of Irish Sea boulder clay known as the Aber Mawr Till. This is a blue-grey, highly calcareous plastic clay. It contains abundant fragments of marine molluscs and carbonised wood, plus a variety of rounded igneous erratics from Southern Scotland and the Lake District, providing strong evidence for the movement of Irish Sea ice sheet southwards towards Pembrokeshire. The till is overlain by a bed of outwash sands and gravels laid down by the retreating ice sheet. Above this lies a rubble drift topped by a sandy loam and blown sand. The rubble drift was described by T. J. Jehu in 1904 as "a rubbly clay, full of boulders of all sizes, most of which are angular and subangular, and derived from rocks in the locality." Today this drift material is recognised as the Upper Head — a periglacial solifluxion deposit incorporating both glacial and fluvioglacial rock fragments.

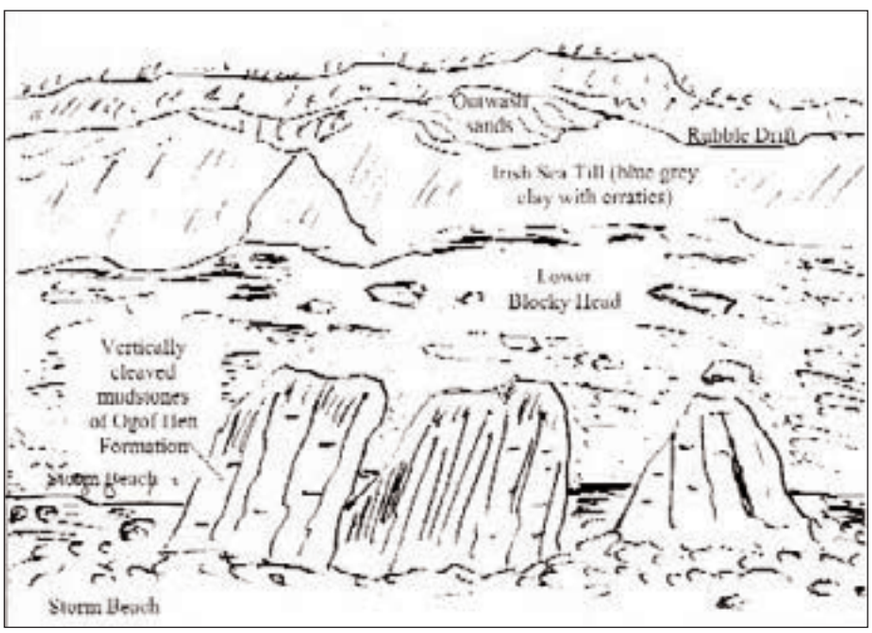

Figure 5 Aber Mawr drift sequence.

5. Whitesand Bay [SM733272] is reached via the B4583 from St David's. Walk from the car park southwards along the beach for *c.* 100m to where the vertical beds of the Menevian Group are planed off and overlain by drift deposits. These consist of *c.* 2m of a raised beach deposit containing well-rounded pebbles and cobbles, some of which are igneous erratics that must be of pre-Ipswichian age. Resting on the raised beach is the Lower Blocky Head, followed by the Irish Sea Till, which in turn is overlain by a rubble drift containing local rock fragments and lenses of sand and gravel. Sandy loam and sand dunes form a recent surface deposit.

6. Ogof Golchfa [SM742237] is located *c.* 200m west of the mouth of Porth Clais harbour. The drift deposits rest on several remnants of a rock platform bevelling steeply inclined Solva beds that are themselves cut by a wide dolerite dyke (Fig. 6, *overleaf*). A raised beach shingle, including some local erratic boulders and pebbles, rests on the undulating eroded rock surface. Overlying the beach deposit is a layer of Lower Head followed by a 2m thick red-brown till laid down by Irish Sea ice advancing SE across North Pembrokeshire during the Late Devensian. As the ice sheet was moving offshore on the south side of the St David's Peninsula, it deposited non-calcareous local till. At Ogof Golchfa there is a variety of local pebbles and rock fragments within the till, including quartz porphyry pebbles from Ramsey Island. Interestingly, a large erratic boulder of Scottish picrite (porphyritic basalt) rested on the cliff top near

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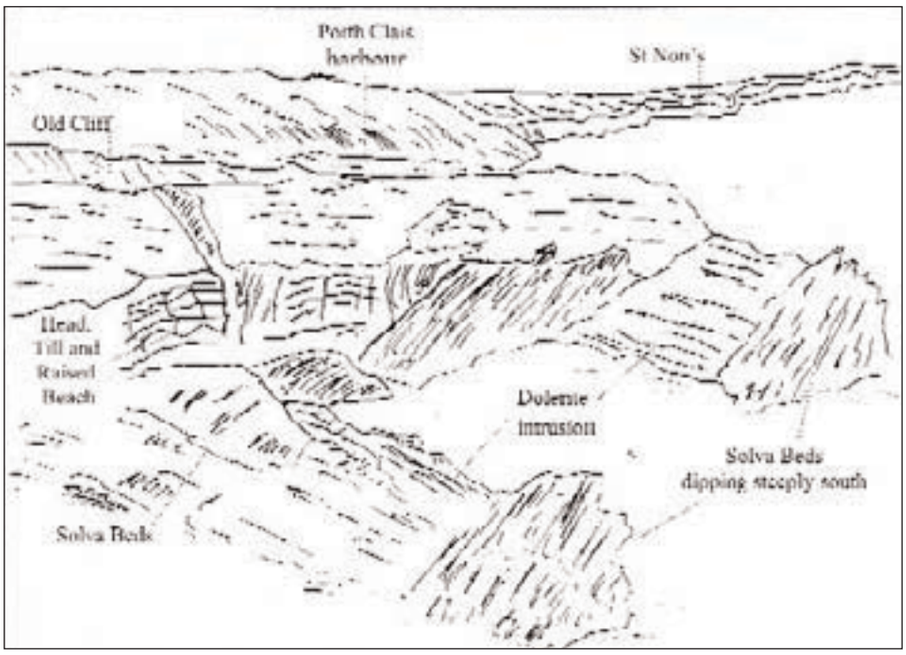

Figure 6 View north-east across Ogof Golchfa Porth Clais.

Walk along the shingle ridge past the flooded pits that are now lagoons supporting a variety of wild life. In the banks of the lagoons there are exposures of glaciofluvial outwash sands and gravel. Pickleridge is a shingle ridge that has developed in a north-westerly direction along the high water mark across the Gann estuary. This shingle barrier impedes the drainage on the marshy flood plain of the River Gann, which is inundated by the sea when there are spring tides. It is worth noting that there is a strong contrast in the natural vegetation between the dense colonies of reed mace (bulrushes) on the wet muddy flood plain of the River Gann and the abundance of gorse and Scots pine that covers the dry sandy slopes of the kame terrace (Fig .8, *opposite*).

Carreg Fran, *c.* 1km west of Ogof Golchfa, until it fell into the sea some years ago. The position of this erratic is marked on the 1:25 000 O.S. map.

7. Druidston Haven [SM862170] lies on the west coast of St Bride's Bay where there is a thick drift sequence plugging a deep meltwater channel. The present storm beach covers the iron-stained and cemented raised beach shingle that is occasionally revealed after high spring tides. The first clearly exposed unit is the Blocky Head, *c.* 2m thick and containing iron-stained quartzite clasts (Fig. 7). This is overlain by 15m of calcareous Irish Sea till, containing igneous erratics, broken mollusc shells and fragments of carbonised wood. The blue-grey boulder clay is being actively eroded by gullying during periods of heavy precipitation. The upper layers of the till contain a high proportion of sand and gravel, which grades upward into rubble drift capped by a sandy loam.

8. Mullock Bridge [SM811080] is located on the B4327 *c.* 3km north of Dale village. This locality is of considerable geomorphological interest, as it provides a magnificent example of a kame terrace on the western side of the Gann estuary. This feature is a flat-topped mound of glaciofluvial sand and gravel that was deposited by meltwater at the junction of the wasting Irish Sea ice front and the valley side. The drift sequence, which was exposed in a large gravel pit *c.* 400m south of Mullock Bridge, was recorded in detail by B. S. John in the late 1960s. Unfortunately, the pit has long been abandoned and is now entirely overgrown. However, the topography of the kame terrace can be appreciated by viewing it from the south in the vicinity of Pickleridge, where there is a car park [SM809067].

9. West Angle Bay [SM853031] is accessed from Angle village in the NW corner of the Pembroke Peninsula. The main drift section extends for *c.* 100m and lies immediately south of the car park. The exposed faces are strongly weathered, such that downwash often obscures the stratification. However, the following units can be identified. Above the present storm beach there is a red, sandy deposit containing pebbles from a raised beach that is now largely covered by shingle. Sub-rounded boulders up to 300mm across also occur in this layer. A distinctive orange unit with large sub-angular clasts forming the Blocky Head can be seen at the northern end of the section adjacent to the sea wall. This is succeeded by a sequence of sands, silts and dark grey clays containing carbonaceous fragments. The dark clays have been washed down to beach level in the centre of the section. A red sand and pebble bed occurs near the top of the cliff, and this may be the product of fluvioglacial outwash from the margins of Late Devensian Irish Sea ice sheet. Sandy loam caps the drift deposits around much of West Angle Bay.

It is worthy of note that the most significant aspect of this site is the existence of a stiff purple-coloured clay containing igneous erratics that was found in excavations made by Dixon (1921) and Bowen (1973). This till lies below the raised beach deposits and therefore must have been laid down by the earlier pre-Ipswichian glaciation. Thus West Angle Bay contains one of the longest sequences of Late Pleistocene deposition in South West Wales,

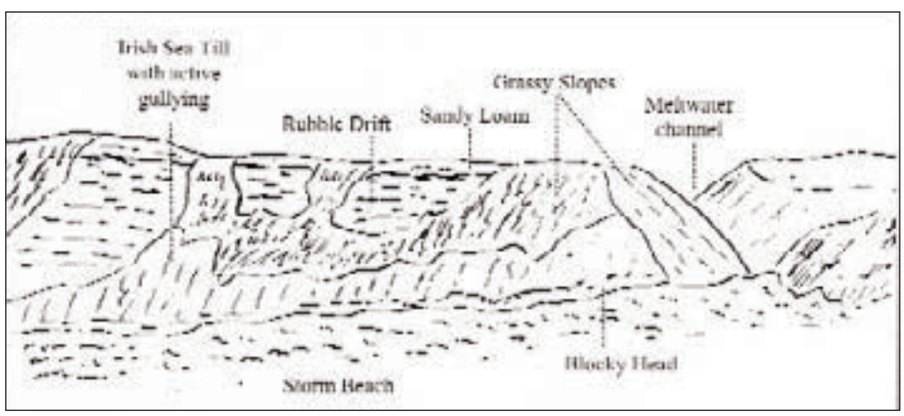

Figure 7 Druidston Haven drift barrier viewed from the beach.

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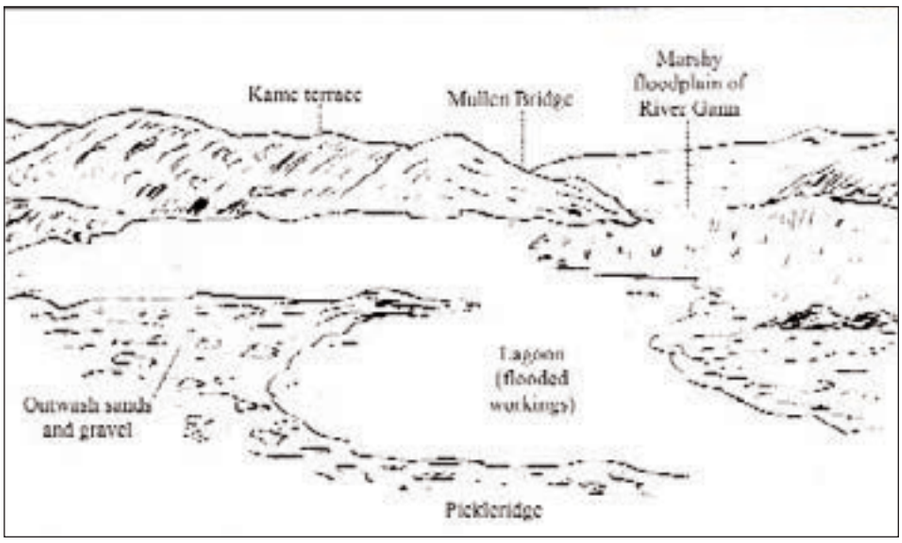

Figure 8 View looking north towards Mullock Bridge kame terrace.

including glacial, interglacial and periglacial sediments ranging in age from *c.* 140,000 to *c.* 10,000 BP.

10. Broad Haven [SR980941] is situated near to the village of Bosherston on the south side of the Pembroke Peninsula. This locality should not to be confused with Broad Haven on St Brides Bay. From the National Trust car park, walk across the beach to the limestone outcrop on the NE side of the bay. At SR980941 the limestone beds that are dipping southwards have been planed off *c.* 3m above the high-water mark (Fig. 9). This platform is covered by the remnants of a raised beach deposit of rounded pebbles and cobbles set in a sandy matrix with patches of cemented shelly deposits in places. However, the raised beach platform is much dissected and eroded by gullies, but it grades upwards into a layer of cemented Blocky Head composed of limestone clasts up to 200mm across. There are also patches of sand rock up to 2m thick that appear to be incorporated into the head deposit. At the top of the section there are exposures of sandy loam and blown sand that form extensive dunes around Broad Haven. The lack of till at this locality and the presence of Blocky Head suggest that the area experienced periglacial conditions, as it was located to the south of the ice front during the Late Devensian.

11. Marros Sands provide an excellent Quaternary section extending from Marros Mill [SN206075] to Raglan Point [SN219072]. The site is best approached via the track leading south from Marros Church, where cars can be parked. Follow the track to Marros Beacon where the route zig-zags down to the coast at Marros Mill. Here there is a low drift cliff behind the storm beach, exposing *c.* 3m of dark brown head containing angular shale fragments and quartzite blocks. This is succeeded by a buff-coloured clay that may represent loess (very fine sand) deposited by wind as the frozen land surface dried out at the end of Devensian times. On the eastern side of the cliff several examples of fossil ice wedges can be seen, where fine sediment now fills the deep cracks that were formerly occupied by ice (Fig. 10, *overleaf*).

Walk along the sands at low tide to the western side of Ragwen Point where the drift cliff rests on a rock platform of Namurian quartzite (the Twrch Sandstone Formation) that dips gently west. Immediately above the platform is a layer of black silt that contains organic remains and this is succeeded by several metres of orange-coloured head. It has been suggested that this silt deposit accumulated in dune slacks when a more temperate environment prevailed before the onset of periglacial conditions. It is important to note that the rock fragments in the head are all locally derived and thus the absence of any erratics suggests that the area lay to the south of the Late Devensian ice margin, where periglacial conditions prevailed.

The fossilized remains of a submerged forest including tree trunks, branches, roots and leaves of oak, hazel and alder, together with peat beds, are exposed at low spring tides on Marros Sands. The sea level was *c.* 20m below Ordnance Datum by *c.* 7,500 BP, when forest growth would have spread well beyond the present coastline. As eustatic sea level continued to rise throughout the Holocene (the Flandrian transgression) the submergence of coastal forests would have occurred.

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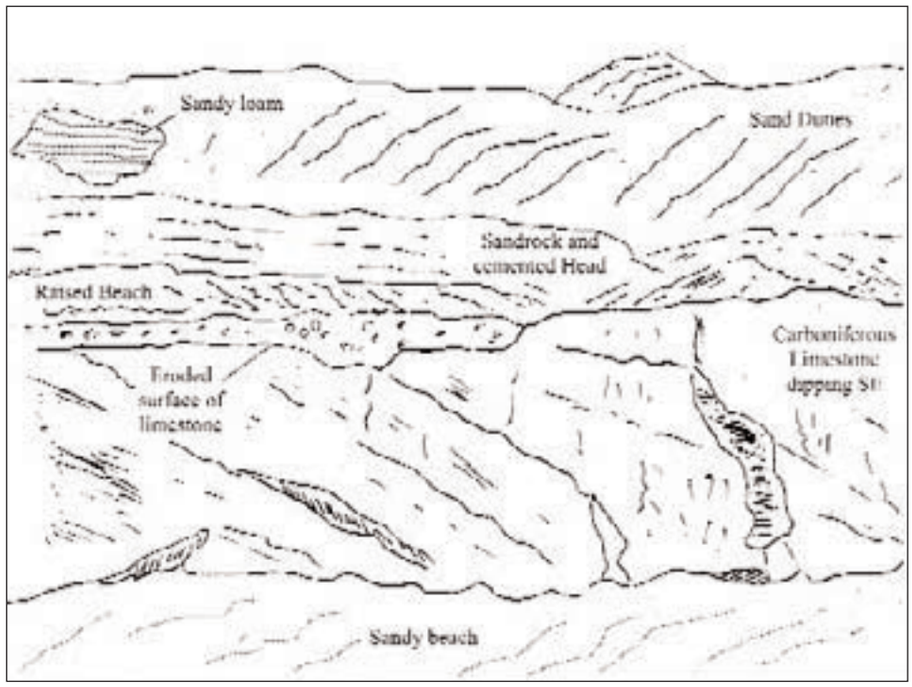

Figure 9 Raised beach at Broad Haven (Bosherston).

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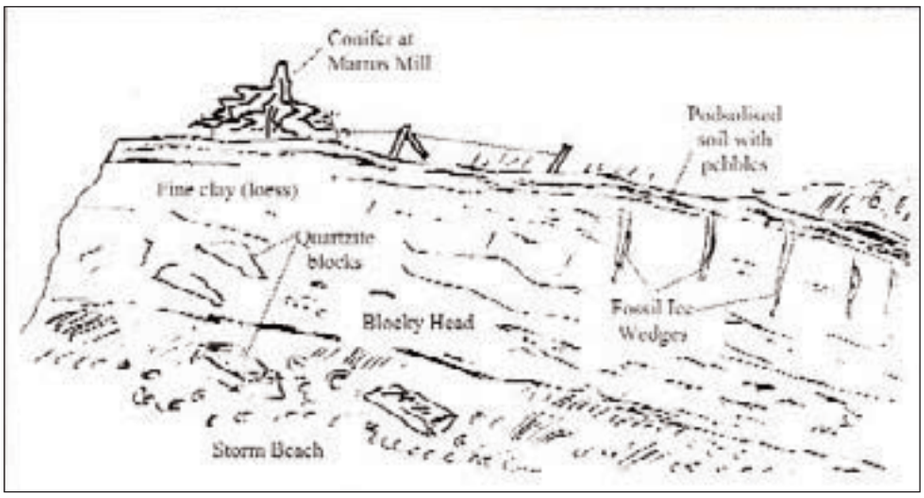

Figure 10 Drift section at Marcos Mill.

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The author

John Downes worked for the OU as an Associate Lecturer from 1976 to 2007. He is now the manager of the South West Wales RIGS group.

Book review

Ensom, Paul 2009 *Yorkshire Geology.* The Dovecote Press Ltd (ISBN 978 1 90434 964 8; hardback, 192pp; £22.50)

This is a fascinating book, well organized and beautifully written. It begins with an account of the social and cultural history that developed in relation to the geology of the large and varied county of Yorkshire. The next two chapters detail the geological history and how this influenced the present day topography. Each of the following chapters explains in time order the rock types to be found in Yorkshire, from Late Precambrian in Chapter 5 to the Holocene and the Present in Chapter 12. The remaining chapters are an account of other remarkable influences and findings and the book concludes with a very useful glossary and a comprehensive list of museums to be found in Yorkshire, plus suggested further reading for those who wish to discover more.

All aspects of the geology and dramatic landscapes, the array of fossils and the minerals to be found are very clearly and fully explained and beautifully illustrated. The artist's environmental reconstructions and palaeographical maps will be particularly helpful to readers new to the subject, and reminders to those returning to it. I believe the author has succeeded in producing a most interesting and very informative account of Yorkshire's long and complex geological history, from the hills and dales, to the cliffs and coasts.

— Jenny Parry BSc (Open)

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Emerging: parallel fragments of a never-ending story

Rob Heslop

"And yet we cannot hope to describe all of the incredible natural happenings (of our World); and thus impossible it seems to be to explain all of these unexplainable things …" — Alleon Dula 1765

Geology and natural history are for me two sides of the same coin; and palaeontology is the common thread.

It has been an interesting year — the 'Darwin Year'. Histories of geology and natural history have abounded; we have heard of names like Lamark, Bonnet, Malthus, Lyell, Grey, Hooker, Wallace and Bates, as well as Darwin, among a whole line of others. All were extraordinary persons, struggling to unravel the strange system of nature's weaving throughout deep time. From the work of these individual a multitude of seemingly parallel intellectual fragments emerged in a relatively short time, and were brought to light as a global, coherent concept. Indeed, the evolution of the natural sciences slowly untangled the sciences of natural evolution. Will we ever leap as far ahead in such a short time again? Or is it from here, only a gradual creep?

The lesser known, but nonetheless charismatic Alleon Dulac was simply born too soon to witness it all, and without the hand of guiding academia, he fumbled in the dark. Yet his work was excellent.

By 1765, J. C. Alleon Dulac (1723–1788), a French lawyer, had published a neat double-volume work concerning the Natural History of the area of Lyon, called *Memoires* (Fig. 1). I struggled to read his works, but as my eyes slowly adapted to the old French text, I truly began to 'see' who Alleon Dulac was. He had attempted to understand the nature of his lands, and was desperate for answers. He was, however, born too soon, for the great list of scientific bibliographies was for him still a generation away.

In book II he describes with verve the geologies of the region, including the thriving quarry trade, the quality of stone, and the strange fossils the quarry folk were regularly finding.

To those at that time, the colourful strata from the mysterious Golden Mountains, just north of Lyon, were as 'old as the whole World'… which was, according to the king's naturalist of that time, the Count G. L. Buffon, 75,000 years old.

Royalist tax collector, and 'well versed' friend of Dulac, Mr Burdin, thought (incorrectly) that the diversity of Lyon rock was due to the collapsing of a huge segment of the earth, sometime after the Great Flood. The seas that had once entirely covered the globe, poured into this collapse, thus revealing for the first time, land; trapped upon this land was a multitude of (fossil) sea shells as well as bizarre (fossil) sea creature remains. The Lyon strata were, claimed Mr Burdin, just one breaking point of this Worldly collapse.

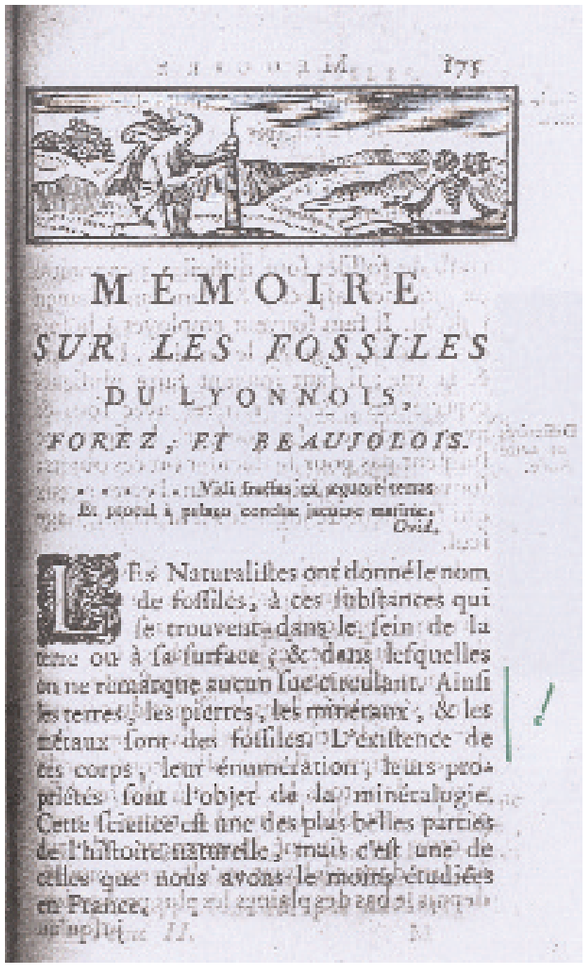
And Dulac also mentioned within his pages the work of an English doctor, J. Woodward, who had even suggested (correctly) an earth 'crust' of stone; a crust that was thought to have several hundreds of leagues in thickness.

During Dulac's time, massive fossil flooded slabs from the abundant Lyon quarries (Fig. 2, *overleaf*) were dragged by cart (and sometimes sailed by boat, down the Soane River), several leagues to the city, and had been used *en masse* to construct not only the many buildings within 'old town' near the river, but also many an ambitious construction throughout the region.

One local aristocrat, for example — an infantry commander named Louis de Melat — had ordered the building of a large private house in his village of Saint Symphorien, in the 1770s, for the sum of £200,000. From within the numerous Lyon quarries, quality stone was carefully selected to pave the ground floor of the Melat construction. Some of it was a yellow-golden coloured; some of it blue-grey, some black, and yet others red.

This assortment had derived from contrasting stratum within the small vicinity of the Golden Mountains. This astonishing variation perplexed Dulac, and despite Burdin's flood-theory, remained at this time a somewhat unexplained curiosity.

Stone for the flooring of the Melat mansion was cut neatly into square paving (*pierres de pavage*), measuring one foot by one foot[1], polished, and laid in a diagonal pattern throughout the plush Symphorien halls. The majority of those old pavings remain to this day, and have been smoothed and scuffed by hurried feet for almost 250 years (Figs 3 and 4, *both overleaf*).



MÉMOIRE
SUR LES FOSSILES
DU LYONNOIS,
FOREZ, ET BEAUJOLOIS.

Vidi fretis, qui jequoreus terras
Et pontus à pulsu concluditur arctior unius.
Ovid.

Les Naturalistes ont donné le nom de fossiles, à ces substances qui se trouvent dans le sein de la terre ou à sa surface, & dans lesquelles on ne remarque aucun suc circulant. Ainsi les terres, les pierres, les minéraux, & les métaux sont des fossiles. L'existence de ces corps, leur énumération, leurs propriétés sont l'objet de la minéralogie. Cette science est une des plus belles parties de l'histoire naturelle, mais c'est une de celles que nous avons le moins étudiées en France.

[1] Feet and inches were at this time still the current system of measurement in France. Later, sometime before the French Revolution of 1789, another Royalist tax collector, Antoine Lavoisier, masterminded the concept of the metric system (based on a division of one ten-millionth of a quarter meridian from pole to equator).

Figure 1 This fascinating chapter concerning the strange fossils in the Golden Mountains region, appears in volume II of Dulac's natural history Memoires.

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Figure 2 An illustration by Dulac depicting a quarry in the Lyon area. During the 18th century, over 50 large quarries in the Golden Mountains prospered. In his work, Dulac gives precious insight concerning the very first quarry folk of the region, the Italian Muratori people, who were working the local stone by the end of the 15th century. Little did he realise, the Romans also exploited these quarries almost 1,700 years beforehand.

These blue-grey pavings imprison a massed multitude of (mostly) single-species fossils, the curved gryphea bivalves. Dulac's work describes them as "… the millions and millions of Griffon's Nails, within the [mostly] blue stone, from the quarries within the near Mountains …". He then names the various individual quarries from which this stone derived, quarries that survive, although now abandoned. I went along to see them.

Other fossils also captivated Dulac, and included 'ammonshorns' (ammonites), and 'fossil minerals' and 'fossil metals', which were considered at this time as the "direct cause of much local disease and illness" " (which explains why Dulac never 'collected' fossils). His country was without doubt according to him, a "vast treasure trove of fossils", for which he proclaimed, "the majority were as of yet, undiscovered "; and on which much "work remains toward their deciphering".[2]

Sometime later, the idea of 'progress' within the natural world was being 'toyed with' and suggested by the Englishman Erasmus Darwin, by the Swiss naturalist C. Bonnet and by the Frenchman J. B. Lamarck. But this idea came too late for Alleon Dulac.

[2] Archaeological remnants were known as 'accidental fossils'.

Figures 3 and 4 In these hallways, on one hand, yellow Aalenian limestone ('Couzon Stone'; few and far between are the fossils here-in)... and on the other, ranging from light grey, blue to black, the Sinemurian limestone. Their colour is due to the presence of fossilized micro organisms (thus leaving a chemical presence within these layers, including bitumen, and iron salts). The Sinemurian stone is loaded with marine fossils.

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Figure 5 A forgotten quarry somewhere in the Golden Mountains. This bioclastic limestone contains many millions of small gryphea fossils, as well as other ancient remains. By the ending of the Great War came the en masse production of concrete. Stone was still dragged from the many Lyon quarries however, but was now crushed and pounded for cement powder. This marked an end of the regional stonemason era; no longer were fossils to be found and collected, for even they were now smashed for dust.

Thus his seemingly unexplainable natural events concerning, among other things, the mysterious appearance of petrified organisms within stone, were about to be systematically interpreted by an array of scientists, as both fossil-rich biostratigraphies (Fig. 5) and inert stone stratigaphies were being chronologically unravelled. Thereafter, the earth sciences were in vogue. Dulac was ahead of his time in that he was seeking a fresh line of thought; he was seemingly atheist, and sought to understand things from a differing perspective.

In 1855, the Melat mansion was sold, and converted to become the local 'town' hall, village school and gendarmerie police station.[3] And effectively by this time, the gryphea limestone had been thoroughly studied, deciphered and eventually dated by French geologist A. d'Orbigny. He had understood that this unusual, multi-seamed stratum (which is up to 15m thick in some areas) was an older sub-stage of the Jurassic Period, and called it the 'Sinemurian' (*sine muros*, meaning oldest rock) (Fig. 6).

Other researchers were to further add to this understanding, such as A. Falsan, and A. Locard, who, sometime before 1866, were together retracing Dulac's Golden Quarry explorations. In their writings there are fewer questions and more fact.

Many thousands of stonemasons still lived in this prosperous region at that time they wrote later, along with the quarry workmen, and farmers, and fruit-growing people. For example, Falson and Locard describe one small village, Villebois, as having more than 2,500 stonemasons. The workers sat on the tiny Villebois village roads, chipping stone day in, day out. Indeed, the whole area bustled with the shaping of Sinemurian black stone, blue stone and the grey stone, and the 'soap stone', which was considered to be a 'bastard, poor quality and crumbly useless rock,' within the Sinemurian. The masons had masses of fossil-flooded limestone to work, and so vast was the quantity of stone that several generations were firmly fixed to the trade.

And still, as in Dulac's time more than a century before, the cobbled roads jostled with loaded carts heading to and from Lyon city, the central exchange area.

Any fossils found were a haphazard bonus for the masons, for their true *raison d'etre*, and indeed value, were now understood. Some of those long-forgotten masons must surely have had impressive fossil collections, and I suspect that many old house attics within the Golden Mountain villages still harbor the odd, dusty fossil treasure.

Falson and Locard quested time and again through the Golden landscape searching and listing some of the remarkable finds at that time, including fossilized wood, ammonites, crustaceans; and at the prolific Saint-Fortunat quarry, fish fossils; and from throughout the entire Sinemurian contexts, masses of the *Gryphea arcuata*.

Other pieces were also described, and collected by Falson and Locard. One from the year of 1850 was exceptional: in the Jurassic Sinemurian quarry of the Arche Vallon, belonging to a certain Sire Turin, the fossil lower jaw from an Ichthyosaur was recovered, and handed to the curator of the Lyon natural history collection, Mr. Jourdan.

Figure 6 "Great winds, and terrible storms have thrown masses of mysterious fossil shells ashore, maybe 50,000 years ago… or were they brought and left later by pilgrims, voyagers and travelers…?" in 1765 a text and ammonite illustration (Lytoceras cornucopiae?) by A.Dulac. Within 80 years of this A. d'Orbigny was to demonstrate a far greater age for the Sinemurian fossil shells (nearing 194 million years), after correlating Jurassic strata and the fossils within them throughout the world.

[3] Thus at a time when E. Darwin's grandson, Charles Darwin, had completed his natural history explorations on the *Beagle*, and was completing the ground-breaking work, *On the Origin of Species*, which was published in 1859.

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Figure 7 Falson/Locard collection. An Sinemurian Ichthyosaur rib fossil.

I set off one blustery autumn day see the Falson and Locard fossils, which are now held by the Confluence Collections in Lyon. I met with palaeontologist, David Besson, and together we sifted the Falson and Locard pieces of the Sinemurian. I saw a multitude of fossil marine reptile fragments (Fig. 7), ammonites, *gryphea* slabes, and petrified fish scales strewn upon a stainless steel medical tray along with faded identification tags, showing Latin species names and quarry find sites. One fossil was missing, the prized Ichthyosaur specimen. We searched through a huge musty catalogue, and found the seven-digit reference number ... but there was no hint as to where the fossil should be; ahh, mystery indeed, and perhaps material for another story.

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Book review

Parfitt, Elisabeth A. and Wilson, Lionel 2008 *Fundamentals of Physical Volcanology*. Oxford: Blackwell (ISBN 978 0 63205 443 5; paperback, 230pp; £32.50)

Effusive; explosive; Hawaiian; flood basalt; Plinian; Strombolian; hydromagmatic — in style and location eruptions are many and varied, but governed by basic physical processes, which Parfitt and Wilson seek to describe while underlining the similarities in eruptions that differ so much in character. The book is developed from an undergraduate course that Wilson taught at the University of Leeds and is described on the jacket as "essential reading for undergraduate students in earth sciences". Wilson has spent 40 years working on understanding the physics of volcanic processes and, developing an interest in lunar eruptions early in the Apollo programme, has since extended his area of study to include other solar system objects.

The introductory chapter describes volcanic systems and gives an indication of the range of volcanic activity, including eruptions and types of deposit. The authors then take a logical approach, examining magma generation, magma movement within the mantle and crust, and magma storage. A number of chapters follow concerned with the movement of magma to the surface and the mechanism of eruption. Volcanic hazards and the effect on climate are also covered, as is volcanism on other planets in some depth.

The style of the book makes it easy to use. The typeface used is clear and the two-column page layout is attractive and a pleasure to read. A glossary is provided at the beginning of the book and new terms are identified by bold text as they are introduced. Diagrams are clear and easy to understand and the text is also supported by good-quality, albeit monochrome, photographs. Equations play a large part in explaining physical processes and where they are used, they are fully explained. Each chapter concludes with a summary, a comprehensive further reading list and a number of 'Questions to think about', the answers for which are provided at the end of the book.

This book lives up to its claim to be essential reading for undergraduates, providing a comprehensive overview of the physical process involved. I found the book enjoyable to read and would thoroughly recommend it to anyone interested in the processes of volcanic eruption.

— Mike Hermolle, BSc (Hons) NatSci (Open)

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Namib to the Cape: OUGS Oxford Branch field trip to Namibia and South Africa (May 27 to June 15 2007), led by Alan Baird

Martin Elsworth (ME), Jenny Elsworth (JE), Chris Hart (CH), Sue Hart (CH), Dan Simon (DS), Anne Wignall (AW), Dave Williams (DW), Paul Speak (PS), Lawrie Bubb (LB), Sylvia Bubb (SB), Carey Shaw (CS), Mary Shaw (MS), Derick Nisbet (DN) and Mary Nisbet (MN)

Fourteen members of the OUGS traveled to southern Africa for a 4,000km natural science adventure, visiting the Namib and Kalahari deserts, the Northern and Western Cape and the Cape Town area (Fig. 1). The trip was organised from the UK by formeer OUGS Chairman David Maddocks, who flew out with the group and drove one of the minibuses. The leader, Alan Baird, drove the other bus. David is a veteran of travels in Africa, and of Namibia in particular, havkng organised several other Namibian expeditions for the OUGS over the years.

Figure 1 At the Tropic of Capricorn.

Introduction *(MS)*

We were met by Alan Baird, geology and wildlife expert at Windhock International airport on 28 May. Having taught geology in the UK, Alan has now settled in Zambia.

This field trip was not purely geological. As soon as we exited the airport the binoculars were out and the bird watching began in earnest — we all got to know the Burchell's glossy starling well. Paul Speak, a keen birder, helped make the endless miles of featureless savannah into an I–spy game of bird-spotting.

After lunch at the Arebbusch Travel Lodge, leader Alan Baird took us all on a walk to a dried-up riverbed where a big sign warned campers of the danger of flooding! The arid area supported Aloe vera, bougainvillea and acacia trees, but there were no giraffes feasting on their leaves or lions lying in their shade. Here we collected and discussed our first geological samples. Next we visited Windhoek itself, where we saw 12 of the Gibeon group of meteorites, the largest shower ever to fall. Found in 1838, they covered an area of *c.* 275km × 100km with 120 specimens, with a combined weight of 25 tonnes. We later saw an eaven larger specimen from the group in the Museum at Cape Town.

One specimen had been sliced to show its iron and nickel content.

May 29: Arebbusch–Desert Homestead (395km) *(JE & ME)*

After stocking up for lunch at a supermarket — our first stop with facilities would be Solitaire, 250km down the road — we soon left behind the familiar trappings of a capital city and began our journey into the *real* Namibia, which in the Nama language means 'huge deserted place'. The metalled road surface soon ended and the stony one began, necessitating an average speed of 50kph. Stretching in front of us was a seemingly endless peneplain, formed by weathering and erosion of ancient mountains, now a desert of parched vegetation and remarkably few trees. Far into the distance was the outline of the Gamsburg plateau (Fig 2). We travelled kilometre after kilometre across metamorphosed rocks, outcropped along the roadside: mica-schist, slates and quartzite. There are formerly buried sediments of the upper Mokolian, formed *c.* 1500Ma ago when the Congo Craton in North Africa and the Kalahari Craton in South Africa collided. Plutons of granite were emplaced in the Damara Mountain Belt, *c.* 540Ma ago, and later uplifted and eroded to form rounded masses called 'koppies' (or kopje; Afrikaans: small isolated hill or prominent pile of rocks). A 'comfort stop' provided us with an opportunity to examine a granite outcrop — revealing a gneissic texture with the usual mica, feldspar and quartz minerals — and our first amazing view of wild life —a sociable weaver's nest, massively perched in a tree. Such nests became a familiar feature, often built in the tree-alternative of telegraph poles. This was followed by the excitement of our first sightings of Springbok, Gemsbok and families of warthogs and baboons. Later we saw kudu, ostriches, a black-backed jackal and numerous unfamiliar birds, including Rüppell's Korhaan, Lappet-faced Vultures and Guinea Fowl.

Figure 2 Heading toward the distant Gamsburg Plateau — a parched landscape with few trees.

We eventually reached the Gamsberg Plateau Pass, from which we could see the Great Gamsberg, to the south. This inselberg of granite has a resistant cap of horizontal quartzite — the Etjo Sandstones, which are petrified desert dunes of Karoo times (180–135Ma). Dipping to the north we could also see a vast plateau of gullies and hillocks ridged with light and dark bands of metamorphic rocks (Fig. 3, *overleaf*).

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Figure 3 The Gamsburg Plateau Pass.

We descended 1000m from the top of the pass, by a steep and winding road, to the junction of the C14, where we turned south towards the Gaub Pass Canyon. This is a dry river crossing, where we stopped for lunch at a formation of concrete table and benches set beside a shady wall of distorted metamorphic rock, which displayed fine examples of boudinaged quartzite.

A surprise strawberry gateau was produced by Alan to celebrate Paul Speak's birthday.

Driving on from the Canyon we arrived at the Tropic of Capricorn, took a group photograph by the sign (encountering other tourists, our only other human contact all day, doing likewise), then drove on between the foot of the Great Escarpment and the eastern edge of the Namib Desert.

The Great Escarpment runs for *c.* 130km and comprises the Gamsburg, the Naukluft and the Zaris Mountains. It was formed on the break-up of the Gondwana continent c. 120Ma ago. On the Namib side of the road the much younger Great Sand Sea of the central Namib Desert is Quaternary in age.

Shortly after the turn off to Sesriem we reached the Desert Homestead, a comfortable farm-style accommodation, where we were welcomed with glasses of fruit juice. From our chalet verandahs there was a view of a now familiar shaped koppie set in an expanse of land covered with tufts of blond dry grass, with a fringe of mountains in the far distance.

May 30: Sossusvlei Dunes and Sesriem Canyon (204km) *(ME & JE)*

Up at 5 a.m. and off to Sesriem and the entrance of the Namib Naukluft Park — the fourth largest nature reserve on earth. As we drove north, dawn broke over the Naukluft mountain ridge, source of much of the sediments through which the Sesriem Canyon has been cut. The park gates are opened at dawn — we were on our way into the Namib Great Sand Sea Desert and some of the highest sand dunes in the world.

The Namib is thought to be the oldest desert in the world, dating from the onset of the Benguela current about 5Ma. This cold current from Antarctica still controls the climate of the desert today. The constant south-westerly wind off the Atlantic is cooled by the current and gets trapped beneath warm continental air, which prevents it from rising to form rain clouds. Some westerly parts of the Namib it has not rained in more than 20 years, although along the coast the cool, moist air forms frequent fogs, providing moisture for plants and animals. Farther east, rainfall

Figure 4 The gesert landscape of the Tsauchab Valley.

rises and run off from the mountains flows westward across the desert (Fig. 4).

Our route into the dunes followed one of these water courses — the Tsauchab — which drains the Naukluft and Zaris mountains. However, the Tsauchab River never makes it to the coast, for its route is blocked about half way there by the desert dunes. The Tsauchab normally appears to be dry, but its course can be seen by the line of (often dead) Camelthorn trees and other vegetation, indicating that there is some underground moisture — a sort of linear oasis. In a good rainy season the river can push its way through to Sossusvlei before sinking into the underlying rocks and following old underground watercourses to the sea. All the soft clayey sediments left behind form the white floor of the 'vlei' (Afrikaans: swampy hollow or shallow lake).

Shortly after coming into the dune area we stopped to examine the *Stipagrostis sabulicola* grasses that stabilise the dunes at the edge of this Great Sand Sea, the low morning sun highlighting the pale fronds against the orange sands. Then, stopping for a "photo opportunity" alongside a dead Camelthorn tree, we spotted the first tyre puncture. After the tyre change, we parked at the 2 × 4 car park and transferred to 4 × 4 'taxis' for the last 5km across soft sand to Sossusvlei (Fig. 5).

Figure 5 The Namib Great Sand Sea Desert has some of the highest sand dunes in the world — Sossusvlei star dune.

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We walked 1km to Deadvlei, a pan now cut off from any water supply by a line of dunes. With no water the Camelthorn trees here have died, leaving their black trunks as silhouettes against the white floor of the pan. With towering red dunes on three sides, the vlei presents an eerie and silent landscape. The colour of these dunes is a spectacular orange-red, enhanced by low morning sun. The colour comes from a coating of iron oxide on the grains, acquired in their long journey from their source along the Orange river, which carries them to the ocean. Once in the ocean the Benguela current sweeps the grains north along the coast until they become trapped in coastal embayments; from these bays the wind carries the grains inland to form the Great Sand Sea. The bases of the dunes and the areas between them are often white, being formed from sediment derived from the local underlying rocks.

The dunes around Deadvlei and Sossusvlei are mainly star dunes, measuring 200–300m from base to crest. They are also relatively static, being kept in place by winds of constant strength but varying direction.

The view from the crest of one of these high dunes is breath-taking and well worth the struggle of climbing the soft sand. Walking along an unbroken ridge is a revelation! You might think that the dune sands are devoid of life, but in fact soon realise from the tracks breaking the clean sand faces that numerous small animals live on them. From Deadvlei we walked to Sossusvlei, where the more energetic of us climbed the nearby tall dune before returning in the 'taxis' to the car park for lunch, where we were soon surrounded by Pied Crows, Cape Sparrows and the odd Pale Chanting Goshawk, all squabbling for the dropped crumbs.

Returning to Sesriem for, we visited nearby Sesriem Canyon, which although a deep, 30m gash in the desert floor is almost hidden from only a few yards away. Even in very dry times water can be found in the narrow upper reaches of the canyon, where evaporation is reduced because of the constant shade (Fig 6).

Figure 6 Sesriem Canyon.

Early travellers and transport-riders made use of this water by tying together leather thongs, made from cattle or Gemsbok hides, and lowering buckets to collect the water. Six thongs were needed to reach the water and so in Afrikaans it became known as 'ses riem' ('six thongs') canyon. In the Tertiary, 30Ma ago, this area was much as it is today, a true arid desert, and covered in sand up to 200m thick, which now forms the Tsondab Sandstone Sequence. Late, when the climate became wetter and caused semi-arid conditions, large rivers began to flow off the Great Escarpment to the east and often reached all the way to the coast. These rivers carried huge amounts of erosion debris over the desert sands to form a 50m thick layer of conglomerates cemented together by the carbonates left behind by the evaporating waters. The worldwide drop in sea level that began *c.* 2Ma ago has caused the Tsauchab River to cut down through these deposits to reach the sea, except that toiay, 65km farther downstream, new dunes block its path beyond Sossusvlei. This cutting process continues today and plant debris caught on the sides of the canyon shows how much the waters can fill the canyon during a good rainy season. The full sequence of deposits left behind by these events can be seen in the canyon walls: fine sands at the bottom and coarser gravels and conglomerate higher up, which, to the initiated, indicates the formation of an alluvial fan.

May 31: Desert Homestead–Canyon Village (520km) *(DN)*

This was a day of traveling. From Sesriem in the Damara we saw intrusions of granite, which streaked out as we gradually climbed the Great Escarpment, extending for some 250km. The escarpment comprises the lower, middle and upper Nama formations. These formed in a marine environment, from erosion products of the Damara Mountains. The contrast between the folded basement rocks and the flat-lying Dama group was marked. After a spectacular climb up the Schwarzrand escarpment we travelled over the flat-lying cap-rocks of the lower Nama group. I can't recall ever having seen such vast expanses of land devoid of physical features. To the west it extends to the next 'step' of the escarpment, but to the east it stretches to the horizon.

The dominant feature of the escarpment to the west is a sequence of black limestones of the Schwartzrand subgroup, representing sediments deposited in an anoxic environment. Clasts of this rock can be seen in the conglomerates of the Sesriem Canyon. Differential erosion has created excellent examples of inselbergs, mesas and buttes. Farther south, the cap rocks are of the upper Nama rocks, representing the Fish River subgroup and predominantly comprising quartzites. There was evidence of a dolerite dyke in the basement rocks below the Nama rocks, which we saw in the Fish River Canyon the following day.

Vegetation is sparse and barely sufficient to support farming. As in many areas of northern Scotland there is evidence of abandoned homesteads and derelict wind-pumps. Grazing for domestic animals has given way to enclosures for game. These occasional prosperous homesteads are separated by vast distances and their owners must have had a special mentality and strength of character to live/exist in these circumstances.

Wildlife is also comparatively scarce – kudu, goshawk and kestrel. There was great excitement when a dead black-backed jackal was found, best viewed from upwind!

We learn in our geology courses that some of the oldest rock on earth had been discovered in Africa, but I was impressed by the age of rocks exposed in this part of Africa more than by anything else, for the Mokolian rocks here existed even before Pangea was formed.

These rocks are the roots of ancient mountain chains formed by the collision of land masses. Highlands were eroded and deposited in large sedimentary basins and the processes repeated, even

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as they are today. We tend to be preoccupied with Phanerozioc ages and accept these geologic processes without thinking about what went before. In Scotland one is aware of the Lewisian at 2,000Ma injected with Laxfordian and Scourian ultra basics; and of the Torridonian at 900Ma, resting unconformably and undeformed on the Lewisian basement. I knew that the Lewisian was the consequence of repeated high-grade metamorphism and that the Torridonian is composed of sediments from pre-existing mountain chains, but I had never really considered how and where they were formed and in what setting of land masses until seeing these Namibian rocks madder me want to find out.

June 1: Fish River Canyon (61km) *(DW)*

The Fish River Canyon is the second largest canyon in the world and, over two waterfalls, the river plunges 550m into a deep canyon 56km long and 27km across its widest point. Although 650km in length from its source in the Naukluft Mountains to its confluence with the Orange River, the Fish River only flows in the rainy season (November to February); during the remainder of the year it comprises only the odd pool. From the central viewpoint the view and the evidence of the geological processes that formed the canyon are superb. Two other viewpoints, each 2km away to east and to west, provide alternative views of the rock formations (Fig. 7).

Figure 7 The Fish River Canyon and meandering Fish River.

Stromatolites at Hikers View Point

The geological formations of the canyon began 350Ma ago, but the rocks cut through by the river are more than 1,000Ma old, as they belong to the Namaqualand Metamorphic Complex (some of the oldest rocks in Namibia, possibly more than 1,500Ma old); and here there are some stromatolite fossils (Fig. 8).

About 800Ma sub-volcanic dolerite dykes penetrated the area and examples of these are visible as large, dark columns. This volcanic activity was followed by extension and erosion, which by *c.* 650Ma left a level mountain root (peneplain) of the former mountain chain. Towards the end of the Precambrian, transgression deposited sediments onto the mountain root: grey-brown quartzites (the Kuibis Formation) and black limestones and schists (the Schwarzrand Formation); after *c.* 100Ma this shallow sea, the Nama Sea, was filled with sediment and became dry, forming a level land surface. The canyon was started to form *c.* 350Ma, forming because of a widespread graben and sub-graben along old tectonic fault zones.

This first Fish River Canyon was about 300m higher than the present canyon. As the hard, resistant quartzite prevented deep erosion, the erosional forces cut laterally, creating the Hums Plateau, a level plain. This feature can be clearly seen from the viewpoints, as the level surface caused large meanders in the river, creating 'cut-off' hills and ox-bow lakes. The Gondwana glaciation caused south-flowing glaciers to fill the graben, grinding it down further. No evidence of the ice ages is present, for the deposits have been totally eroded. The break-up of Gondwana *c.* 120Ma ago, and the associated up-lifting of the Great Escarpment, eventually caused the formation of the younger part of the Fish River Canyon. The resulting increase in gradient intensified erosion and the canyon cut deeper into the existing river loops.

Over millions of years the river has cut through the hard quartzites of the Hums Plateau and reached the ancient rocks of the Namaqualand Metamorphic Complex described earlier. These rocks outcrop in the bottom of the canyon and are the deepest rocks in southern Namibia.

Figure 8 Stromatolites at Hikers View Point.

Canyon Village

Ambitious hikers can descend into the canyon to its floor, for a 3–5 day hike to Ai-Ais 60km distant. At Ai-Ais there are hot springs — discovered in 1850 by a Nama sheep herder — which result from a deep fault system in the canton area. Ai-Ais is a Nama word meaning 'very hot' — the water reaches 600C. The water is rich in sulphates, chlorides and fluorites and is reputed to have therapeutic values for rheumatic pains. (Note: For safety reasons, a special Namibian government permit is required to enter the canyon.)

June 2: Canyon Village–Twee Rivieren (497km) *(CSh)*

With a driving surface of dolerite gravel on the Nama group, we realised why this makes such good road material as we sped past the springboks, zebras, oryx and ostriches, back to the more major road and railway on the Karoo sequence sands and tillites.

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Our route took us past the Naute dam and reservoir that supplies Seeheim, an oasis in the scrub, with citrus orchards and market gardens for 5km around the base of the dam.

We reached Keetmanshoop (a Southern African crossroads) by 10am, changed tyres and sped on towards the game reserve on the borders between South Africa, Namibia and Botswana.

The next part of our journey took us across more weathered dolerite sills, an area known as the Giant's Playground, with huge dolerite boulders littered across the landscape and relatively little wildlife, but sheep and goats in the scrub. The terrain here (e.g. Aroab township) is interspersed with salt pans (evaporites) and some aeolian sand, to the South African border at Rietfontein.

The game reserve, and our accommodation inside it, was still about two hour's drive away, so we sped off through, with only short stops to view, saltpans, scrub and semi-desert to Bokspits, then along the Botswana border, the dry gravel bed of the Nossob River and into the Kalahari Desert, with only 15 minutes to spare before the gates were locked at sunset.

June 3: Kgalagadi Transfrontier Park (124km) *(PS)*

Our first game drive in the Kalahari. The morning light improved as we drove up the dry valley of the Nossob River. A group of ostriches provided the first photographic opportunity of the day, followed by a bachelor herd of about ten springbok (Fig. 9) and the first of several oryx (gemsbok). An Eagle Owl was spotted in a tree; then a Pale Chanting Goshawk in another tree. But the next raptors were something new: a group of Lanner Falcons eating something on the salt pan. Two Tawny Eagles, more Lanners and a distant Bateleur followed.

Figure 9 Springboks in Kgalagadi Transfrontier Park.

Then the front van halted again and suddenly the birds gave way to cats: two young male lions, snoozing in the morning sun beneath a large bush a few hundred metres away. They looked well fed, presumably having made a kill overnight. We watched for some time, admiring their magnificent manes, but they did not seem inclined to move until sudeenly one rose, slowly walked around his brother and flopped down again (Fig. 10).

A nearby waterhole was devoid of life — obviously herbivores felt that it was too close to the lions. More birds were spotted: Lanners, a Kori Bustard and a pair of Lappet-faced Vultures in a tree. Had they finished off the lions' meal?

Figure 10 Lions! ...

A nearby White-backed Vulture supported this suggestion. Suddenly the front van stopped again and we were stunned to see a fine male cheetah leap up in surprise about 20m away! To our delight it decided that we were no threat and took its time, spraying the tree under which it had been snoozing before wandering slowly off through the bush, followed at a respectful distance by a Black-backed Jackal (Figs 11 and 12). As camera shutters clicked, the cheetah called softly and looked around, obviously looking for its friend or mate. Delight turned to amazement when it turned back towards us and walked around for several minutes before heading off, still followed by its attendant jackal.

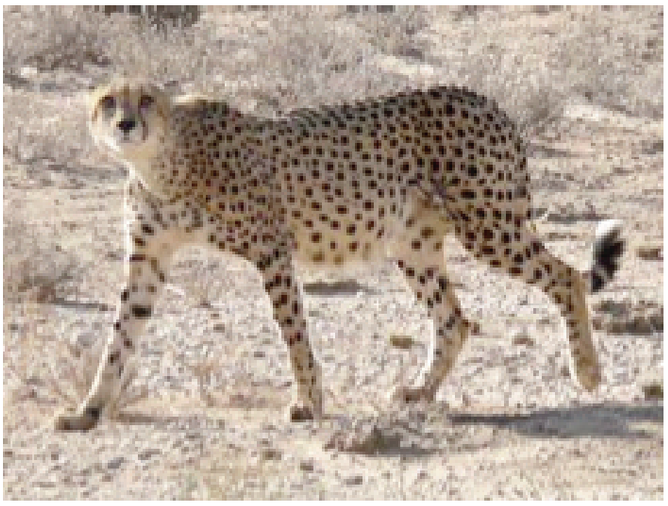

Figure 11 ... and a cheetah ...

Figure 12 ... and his wary companion, a Black-backed jackel.

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After our lunch break at Melkvlei we returned by the same route. The cheetah had gone, but the jackal and the two lions were still there, and we had close views of wildebeest and a red hartebeest, and springbok and several Namaqua Doves at a pool.

Then, beneath a tree, we saw the national bird of Namibia: the Crimson-breasted Shrike, its bright crimson breast is a truly stunning colour (Fig. 13)! And finally, the highlight for some: a pair of ostriches with seven chicks.

Back at our camp, our lunch break became lunchtime for small wildlife as well: Yellow-billed Hornbills (Fig. 14), several other species of small birds, ground squirrels and several yellow mongooses (Fig. 15).

At 17.00 we gathered for a night game drive, apparently something of a park experiment with us as guinea pigs. On ranger swept a spotlight across the countryside looking for reflections from eyes as the other drove. In the dusk we saw the same herbivores as in the morning, but soon nocturnal species began to appear: a Spotted Genet up a tree, climbing about on a Sociable Weaver's nest looking for a meal; a Cape Fox, a Bat-eared Fox, two African wildcats and a number of Spring Hares (rodents, not hares, which hopped along on huge back legs, earning them the nickname of kangaroo rats).

Figure 13 Crimson-breasted Shrike: Namibia's nationl bird.

Figure 14 A Yellow-billed Hornbill.

Figure 15 An alert Yellow mongoose.

June 4: Kgalagadi Transfrontier Park (96km)*(PS)*

The Kalahari dunes are the topmost level of the Kalahari Group, a thick pile of sediments covering a huge area of southern Africa and thought to have been deposited since the breakup of Gondwana some 130Ma ago. The dunes themselves are long, roughly linear features, in this area aligned roughly NW–SE. They are *c.* 5–10m high and separated by *c.* 50–100m of flatter terrain. The sands themselves are classically aeolian, with well-rounded grains and very red in colour. The dunes are quite well vegetated with an assortment of grasses, low scrub and occasional larger camelthorn trees. This indicates that they are stable, having remained much the same since the last glacial period, 16,000 to 20,000 years ago. There is little rain (although there had been a rare downpour a few days before our visit) and the rivers have not flowed for some 50–70 years!

The track mainly follows the interdune areas, occasionally turning to cross one of the dune ridges, and by this means we progressed across to the course of the second of the two rivers of Twee Rivieren, the Auob. Like the Nossob, it is in a flat-bottomed valley 20–30m deep. The bottom is sparsely vegetated and whiter than the dunes, with a harder surface cemented by calcrete. But the main exposure of calcrete, and indeed the only thing that could really be described as 'rock' is at the top edges of the valley sides. Here it takes on the appearance of a limestone outcrop, a few metres thick, with caves within and beneath. They looked ideal as leopard dens, especially where partly hidden by bushes, and we decided we were probably being watched from within.

The wildlife this day was similar to yesterday's, including two male lions but no cheetah. There was, however, one bit of excitement, when ace wildlife-spotter Sue shouted 'snake!' Just at the edge of the road was a puff adder: "A slow-moving, bad-tempered and excitable snake... when annoyed, it strikes vigorously in all directions", according to a snake website. From within the van we avoided annoying it and concentrated on photography, before it slowly squeezed into a nearby narrow hole.

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At Auchterlonie we turned off the riverbed track towards a small group of buildings perched on the valley rim, a small museum in a restored farmstead built by the Human family in 1913. Conditions here were spartan in the extreme and the Humans survived by hunting and sheep-farming, in temperatures that reach 40C in summer. The nearest town, Upington, is 14 days away by oxcart — a month's round trip to go to the shop!

After lunch we had a short late-afternoon drive up the Auob Valley. This was our last chance to see one of the park's specialities, and one of Sue's target species: meerkats. A first spotting turned out to be ground squirrels, but soon one meerkat appeared. It was rather distant, but stood propped up on its tail in true meerkat fashion, just about within photographic range.

June 5: Twee Riviere –Augrabies (419km) *(DS & AW)*

In an early game drive we spotted a magnificent Secretary Bird (Fig. 16) before heading for Augrabies Falls. South 200km to Upington is initially through the Kalahari dunes before an increasingly flat and featureless landscape with hardly a building to be seen. We then headed west along the Orange River Valley, much more populated and verdant, particularly with vines. After *c.* 100km we came to our first sight of the Orange River, at Kakamas, and increasingly mountainous scenery. The rocks are of the Namaqualand Metamorphic Complex, seen before in the Fish River area; *c.* 1km west of Kakamas we stopped to look at some superb augen gneiss right by the roadside.

Figure 16 A Secretary Bird.

June 6: Augrabies National Park *(DS & AW)*

We started the day with a short walk to the Augrabies Falls (Fig. 17). Although it was the drier part of the year there was still a large flow over the drop of more than 60m. The Orange River rises in the central part of South Africa, and has a huge catchment area. Downstream of the falls there is an 18km gorge, the river losing another 34m down rapids. The falls are in granitic gneiss, all still part of the Namaqualand Metamorphic Complex. During the walk we came across intrusive veins with a mineralization, which may have been tourmaline. As at the Fish River, there were also dolerite dykes in the area. Some of us continued with a 5km interpretative trail, taking in the superb view of the dolerite dykes at Arrow Point, and of where the gorge spilts into two for several hundred meters.

Others, relaxing at the lodge, saw baboons and dassies (also called rock hyraxes) and lovely, almost tame birds, including Bulbuls and Orange River White Eyes. One baboon in particular took a great deal of interest in the private activities of our group, peering intently into each room.

Figure 17 Augrabies Falls.

June 7: Augrabies–Okiep Country Hotel (335km) *(LB)*

This route traversed the transition from a warm, arid/semi-arid environment across the watershed to a well-vegetated wet, cold environment. The day started idyllically with sunrise over the distant hills casting long shadows across the plain, and a few last photographs of the Orange River plunging over the rounded exfoliating granite of the Augrabies Falls.

The straight N14 passes through grape vines and orange groves, and increasingly lush vegetation towards the coast, across the gently sloping Bushman land peneplain, carved flat by the present cycle of erosion. Towards Okiep there were signs that the early rains were encouraging plants to flower with the prospect of an early spring. Sociable Weaver Bird nests topped many of the roadside telegraph poles.

With a lowering of relative sea level over the past 100Ma the former plain has been incised by valleys, which have widened to become the present plains. Puncturing the present plain are flat-topped massifs and ridges representing remnants of the last cycle of erosion when the plains were several hundred metres higher than now. The flat tops represent erosion surfaces and are not associated with bedding, as the gneissic terrain of the Namaqualand Metamorphic Province that forms the massifs is heavily contorted. On the north side is a darker ridge that represents a mafic or ultramafic intrusive rock. cutting the gneiss; this is possibly associated with the 900m wide dyke seen from the rim of Augrabies Falls. In some places distinctively coloured Kalahari dune sand formed sinuous seif dunes, at one point hard against the flank of an inselberg.

Conspicuously scattered along the roadside are pegmatite boulders and cobbles, their white colour indicating the line of pegmatite dykes cutting through the amphibolite. We stopped at one of these dykes where the quartz was pink, bordering rose quartz (Fig. 18, *overleaf*). The dyke was *c.* 3m to 4m wide, injected through decayed amphibolite showing well formed blades of hornblende, the decay possibly by reaction with superheated steam and gases during injection or contemporary

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Figure 18 Weathered, white pegmatite boulders shwoinf the line of a dyke injected through decayied amphibolite in the Namaqualand Metamorphic Province.

weathering of mafic minerals. The pink areas of the quartz show a lattice pattern that we were unable to explain. The *c.* 100mm long crystals of feldspar are perthite, an alkali feldspar falling on the Na-K leg of the triangular composition diagram.

Large bags of rose quartz hand specimens were available at the filling station in Pofadder.

We passed by two large adits in the side of a plateau — prospect adits made to evaluate the Gamsberg sulphide deposit discovered in 1971. A large opencast mine was proposed in 1999, which would create a hole 2km × 3km × 600m deep! However, an environmental impact assessment argued that this area of Bushman land was very sensitive and the mine was opposed by conservation NGOs. This opposition and low zinc prices delayed mining and provided an opportunity for further consultation and a partnership agreement to be reached meeting biodiversity conservation targets. The ore body is low grade and mine development is currently on hold awaiting the price of zinc to rise.

Aggeneys village and mine nestle under Black Mountain. The mine has a chequered commercial history dating back to 1968. There are large deposits of ore containing lead, zinc, copper and silver, but of the four bodies only one is currently being mined and one is being prepared. The ore grade is too low for major profitable mining, but it is probably only a matter of time before either extraction technology improves or commodity prices increase to enable the mine to enter full production.

Familiar red dunes mark the broad Koa Valley, where millions of years ago the Orange River flowed, a quick search for water-rounded pebbles was unsuccessful, but flash floods can easily cover all evidence. The showers were becoming far more frequent now, and there were pools of water in the stream-beds alongside of the road. Foliating granite gneiss domes of the Namaqualand Metamorphic Province pepper the landscape, creating a rain shadow to the east, many covered with vegetation.

Turning off the N14 we headed to the copper mining town of Carolusberg, intendeing to visit the copper mine, but the rains had made the track muddy and nearly impassable so we turned back (Fig. 19).

Figure 19 A copper mine near Carolusberg.

June 8: Okiep mining area (52km) *(SH & CH)*

"Just like Scotland; cold, wet and unpleasant," so said one of our party on seeing yet more rain at breakfast.

We visited the small mining town of Nababeep; the copper mine is visible on the hillside from virtually everywhere, and there is now much unemployment. But the town has an absolute treasure in its museum — not so much the artefacts themselves, although they were very good, but the curator, who had such a passion for the subject that we all forgot the rain and became engrossed in her storytelling. She was a German lady who had somehow found her way to this small mining community and settled here some years ago. Incredibly enthusiastic, she led us through the rooms of the museum where much care had been taken to display the process of mining in Nababeep and the surrounding towns. She showed us photographs of the local smelter, from the 1940s, when the town smelted for seven local mines, getting to a temperature of 1260C, but which has now cessed. There is an 8ft × 8ft wall display showing the whole mine in section, providing a clear idea of the scale and extent of the mine. There are display cabinets with marvellous specimens of chrystalline chalcopyrite, beryl and even gold ore from one of the sister mines of the O'Okiep Copper Company Ltd, the company that owns all the local mines. There were some stunning statistics — e.g. it takes one tonne of rock to produce just six grams of copper ore. However, other than the curator herself, my lasting memory of the museum is of the intricate 3-D models of the tunnel structures of the local mines, or rather, of one particular model: in a glass cabinet, this model originally was about four feet high, and about the same depth; it must have taken many hours to construct; but, in 1949 the model collapsed, and has remained in the cabinet, collapsed, for the last 58 years.

The museum grounds contain many restored and brightly painted pieces of machinery and engines and we picked up small rock specimens. As we walked back to the minibus a local man came up to us with rock specimens from his pockets — galina, bornite and garnets — which he was selling for a few pence each — cheap to us, but another reminder of the poverty around us. (The museum admission was just one Rand — less than 10p — clearly not there to make money!)

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Figure 20 Orbicular Diorite boulder (lens cap is 72mm in diameter).

Although we drove up to the mine itself, the manager was concerned about the amount of rain that had fallen in the last few days and the safety, so would not allow us entry. A sign at the entrance emphasizes the issues, stating that although the mine has a five-star safety grading it had been only 530 days since the last disabling injury, and 608 days since a reportable injury.

We next drove to Concordia, to inspect one of the mysteries of geology: orbicular diorite (Fig. 20). It seems to be a well-known mystery because we followed signs to 'Orbicule', along a lengthy gravel track to a sandy parking area at the base of a small hill, from which a path led up to the rock face.

The tourist literature states that this rare rock texture came about when granitoid magmas separated while in a fluid state. One granite type formed ovoid 'orbs' showing concentric internal banding, within a groundmass of a slightly different composition. One of the group asked, "Why is there quartzite between the orbicules?" Nobody had even a theory as to why, so here is a PhD subject for someone.

We next visited the mine Pump House next to the hotel. For all the world we could have been in Cornwall! Okiep Cornish Beam Pump was erected in 1882, designed by J. Hocking of Redruth and manufactured by Harvey and Co. of Hayle. The 'bob' or beam is 32ft long, weights 25,000lb and was shipped to Namaqualand from Cornwall. In 1896 the engine used 357 tonnes of coal — imported from Wales (Fig. 21)! The engine stopped work in 1930, but the O'Okiep Copper Company restored the engine and in 1961 it became a National Monument. We climbed to the top, marvelling at the engineering, and at the distance the machinery had travelled to get here.

June 9: Okiep Country Hote –Clanwilliam (475km) *(CS)*

We left Okiep to travel down the N7, to Springbok and beyond, through the Namaqualand basement rocks of the Mokolian (1000Ma+), climbing through the gneisses (often in cuttings in the Burkes Pass area) towards Kamieskroon. The area, however, was far from bereft of wildlife: baboons darted across the road and sacred ibises came into view as we climbed.

Figure 21 The Cornish Beam Engine at Okiep.

Some of the gneisses were closer to the mafic end of the spectrum than others but the whaleback exfoliating domes of granites were unmistakeable. There was also plenty of evidence of weathering of pegmatites to kaolin.

After Garies, the geology becomes more varied. The Gariep super-group (containing more manganese) of Namibian age (800–1000Ma) replaces the slightly older Namaqua formations near Bitterfontein (the railhead for building stone for the south). At Vanrhynsdorp we made a detour east to climb the escarpment towards Calvinia, turning off at Nieuwoudtville to view evidence of Mesozoic glaciation — a glacial pavement with distinctive ridging, and at another site dropstones in the siltstones and shales (Fig. 22). The return down the escarpment provides spectacular views of the braided river system of the Sout and of the Precambrian calcretes, shales and sandstones of the escarpment.

Figure 22 Mesozoic glacial striations near Nieuwoudtville.

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Back on the N7 we continued south into the Oliphant River system, continuing upstream. The road cuttings provide good outcrops of concentrated manganese in the remains of the Gariep group; and next on to the younger rocks of the Table Mountain group (500–400Ma).

June 10: Lambert's Bay (146km) *(JE & ME)*

Original plans for exploring the nearby Cedarberg Plateau were abandoned because of inclement weather. Instead we visited Clanwilliam Dam on the Olipohants River (Figs 23 and 24), a tea plantation and the Atlantic Coast at Lamberts Bay (Fig. 25). Here the nutrient-rich cold waters of the Benguela current offshore provide an abundant source of fish.

Not one to miss a geological moment, Alan showed us how the features of present-day shells could also be found in fossilised shelly remains. Next we returned to the harbour and crossed to Bird Island — an outcrop of weathered and white-stained Table Mountain Group Sandstones, comprising a well sorted quartz sand with occasional pebble clasts deposited *c.* 510–500Ma ago. The environment of their deposition, whether fluvial or marine, is debatable (Compton 2004), because of a lack of fossils. The island is now a nature reserve and is home to many birds, mainly cormorants and gannets, and to a colony of Cape fur seals. It was a noisy and pongy place, though it is said to be worse in the breeding season when many more birds are at home. Non-geological 'White Gold' — Guano — used to be a valuable source of fertiliser.

After lunch we visited the Groenkol Rooibos (red bush) Tea Estate. Our hosts, Chris and Annette, provided an informative explanation of tea production. In this area, conditions are ideal for the plant, *Aspalathus linearis*, mainly owing to the light sandy soil (thanks to TMG sandstone, ex-Cedarberg), and to wet winters and hot, dry summers. We learned about the management of the six-year growth cycle of the bush and were taken to see the processing plant — a moment of hilarity was had when we were made to don unflattering protective masks and mobcaps before being allowed into the works.

Figures 23 and 24 Oliphants River and the Clanwilliam Dam.

Initially, the bundles of red twigs are chopped, soaked with water and spread to dry outside before being taken into the plant to be blended, graded, sterilised and further dried before being sent to market. Ninety-five percent of the tea is bagged and shipped all over the world.

Back at the house, stopping to examine a flowering *protea* bush on the way, we were served a mulled concoction of rooibos and apple juice flavoured with cloves, star anise and cinnamon stick. While we enjoyed the drink Chris told us about the *fynbos*, his 'paradise on earth' because of the huge diversity of species that grow there, including the fabulous Proteas, and of the spectacular displays of flowers in the spring and summer. We were also given an insight into plants pollination strategies and survival in conditions of heat and drought.

Rooibos is an aromatic tea, which claims healthy properties and is caffeine free. It is an acquired taste! For more details see www.africandawn.com

Figures 25 Seals and gannets at Lamberts Bay.)

June 11: Clanwilliam–Cape Town (322km) *(CH & SH)*

Leaving Clanwilliam, after gift-shopping at a craft shop we passed the dam at Olifants River. Upstream there were spoonbills in the water and, following the river for some time, we could see how verdant the vegetation had become as a result of the rains. We passed orange and lemon groves, sweet potato and melon fields, then drove through the Picketberg Pass. The scenery would have been absolutely spectacular — if only we could have seen it through the rain and clouds. But we did see birds, especially hundreds of flamingos in the lake at Velddrif.

Our destination was the West Coast Fossil Park a few kilometres south of Velddrif. Here in 1958, while working the opencast phosphate mine, a mineworker found a fossil. Mining continued and it is estimated that the mining company had removed 80% of the fossils before mining in the area ceased! Now there is a partnership between mining company bhpbilliton and Iziko museums of Cape Town; a 'green' village has been settled with ex-mine workers and the Vula Environmental Company has rehabitated the area with fynbos (the classic vegetation of South Africa).

Now the focus is on education and research, and tourism brings much needed cash to the area. After watching an informative video we braved the rain to visit the fossil site. The probable site of a palaeoriver channel *c.* 5Ma years ago, the fossils arrived here during a catastrophic flood. Geraldine, our guide, suggested that a phosphate bank had stopped the fossils being washed out to sea.

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Figures 26 and 27 The fossil bone beds near Velddrif.

We struggled with this suggestion because there appeared to be hundreds of fossils on both sides of the bank — yes, hundreds, if not thousands (Figs 26 and 27).

There were four fossil beds being excavated, and each contained fossils of Sivathene jaws — a short necked, long-horned giraffe, whale vertebra, small hind quarter bones of a three-toed sabre-toothed cat, African bear, okapi, Gomphothene (small African elephant), and other amphibians, reptiles and birds. The quantity being excavated was truly astonishing. In the rain it was not possible to take an opportunity to sift soil for fossils, so we visited the laboratory instead. Here there are bones of extant animals to help the 'cleaners' identify the fossil remains.

June 12: Cape Town area (102km) *(SB)*

With a clearer sky, we ascended Table Mountain (1086m) in the cable car. The flora is quite beautiful: another example of Cape fynbos. Some of the ericas are in bloom and other flowers (Fig. 28).

Geologically what you see looking at the mountain from its base is a basement of shales comprising deep-water deposits laid down *c.* 800Ma ago. These Precambrian Malmesbury shales, which are not as resistant to weathering as the sandstones above them, have been heavily folded and altered; and were intruded by Cape Granites *c*. 600Ma ago.

Figure 28 Table Mountain, South Africa.

There are good views of the shales and granite on the drive up to the cable car. The shales were eroded underwater, but from 450Ma (during the Ordovician) sediment from rivers created layers of sandstone in a delta. This is the Table Mountain Sandstone (TMS), part of the Table Mountain Group (TMG). The vertical grey crags that can be seen from the cable car are the highly resistant TMS: in places it is fine sandstone, but it is much coarser elsewhere.

When Africa was part of Pangaea, *c.* 300Ma ago, glaciers flattened the surface of the sandstone; glacial deposits can be seen at Maclear's Beacon at the summit. During the break up of Pangaea and later of Gondwanaland, Table Mountain began to rise above sea level in isostatic adjustment. The shear south face of the mountain was caused by the action of waves forming a sea cliff. Many of these geological features can be seen from Signal Hill.

We next explored Chapman's Peak Drive, a toll road blasted out along the side of Table Mountain, and where evidence of the palaeoenvironments can be seen, although much of their interpretation is still controversial.

The exposures show the 600Ma old granite overlain unconformably by 550m of sandstone, siltstone and mudstone of the Graafwater and Peninsula formations of the TMG. These formations were deposited *c.* 450Ma ago. There are large throw faults displacing the beds and in places the unconformity contact is irregular, with 3m depressions in the granite surface (Fig. 29, *overleaf*).

The sedimentary rocks were deposited on a huge coastal plain, the rivers draining from the north towards the present-day Cape coast. On the plain the velocity slowed and channels split into smaller, shallower streams, depositing alternate layers of sand, silt and mud to form the Graafwater Formation. The climate during this period was warm and dry (not like the weather we had) and the surfaces dried out, creating cracks that later became filled with sand (Fig. 30, *overleaf*). Continued drying caused contortions and these can be seen along the drive. The coastal plain continued to be flooded at times and large amounts of sand were deposited.

The sandstones show many typical sedimentary structures: cross bedding, scour and fill, flat bedding, ripples and trace fossils. The ripples themselves are varied, and include interference ripples, flat-topped ripples, double-crested ripples and ladder-back ripples. These, together with marks made by marine organisms, suggest that there was periodic marine influence. Mud continued to be deposited and reworked forming thin layers and lenses, even mud flakes, which were later incorporated

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Figure 29 Chapman's Peak drive: the spectacular road follows the unconformity between the granite and the Table Mountain Group.

into the sand. The cracks indicate that the time periods of surface exposure between floodings were quite short. Stones deposited at this time can be traced from the north towards Chapman's point. Gradually the alluvial plain extended seaward and buried the coastal plain with sand and gravel, evident in the abrupt change from thinly bedded sandstones, siltstones and mudstone to the more thickly bedded alluvial sandstones of the Peninsula Formation in the cliffs above.

At Simonstown, on the beach we were shown huge boulders of Cape Granite with large feldspars and variously sized xenoliths of Malmesbury hornfels, some of which are believed to be migmatite.

Farther along the coast one of the big tourist attractions in this area is its penguin colony. Formerly known as 'Jackass' penguins, these are now called African penguins (Fig. 31). We were lucky, as June is the breeding season so we were able to see quite a few young in the burrows. To round off our truly amazing day we are treated to the sight of a whale venting some way offshore, a passing sea kayaker, a naval ship undergoing sea trials and a wading Greater Speak — a rare spotting in these waters.

Figure 31 The Jackass or African penguin.

Figure 30 Sedimentary structures in the Table Mountain sandstones.

June 13: Cape Town area (62km) *(MN)*

The treat of the day was the Kirstenbosch National Botanical Gardens. These gardens are certainly one of Capetown's treasures – a pleasure for serious botanists, and for families just enjoying a day out. The flowers are beautiful, especially the proteas and the fynbos. The birds, especially the sugarbirds, were there to be photographed. The scents from the herb garden are almost overpowering. Special features include the 'Colonel's bird bath', 'Harold Pearson's grave' with its granite Celtic cross and the conservatory with the baobab tree.

Geology for the day, for some, was done at Sea Point, where the sedimentary rocks of the Malmsebury Group (560–540Ma) and the Cape Granite (540Ma) are exposed on the foreshore. The former, which are predominantly shales and muddy sands, were laid down in a marine environment lying between Africa and South America. As the ocean closed by subduction under Africa the shales formed a wedge against the South African continent into which the Cape Granite was intruded.

At Sea Point the contact metamorphism between these two rock types can be inspected. The granite had cooled slowly, creating feldspar phenocrysts up to 80mm long. Working from the granite towards the sediments there were initially xenoliths of Malmsebury, identified by their black colour, followed by a region where there were interwoven bands of granite and sediments, some of the igneous rock being microgranites. The central point of contact is difficult to locate (Fig. 32, *opposite*).

Beyond this there is a zone where the baking of the shales by the high temperature granite had produced a hornfels structure, which is both hard and brittle. The grade of metamorphism is indicated by the presence of cordierite crystals, which prompted much memory searching as to just which grade was indicated.

At the start of this excusion a pod of dolphins was seen, and after returning to the promenade a hump-back whale was spotted relatively close to the shore, swimming south.

June 14: Cape Tow –airport (28km) *(DM)*

On our final day in Cape Town some of us visited the Natural History Museum, where one of the exhibits was of the Namibian Gibeon meteorites. How appropriate that we should finish our African journey with this lump of iron/nickel as we started it 18 days earlier with the Gibeon meteorites in Windhoek.

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LB & SB: 18, 19, 28, 30
ME: 2, 3, 4, 6, 23, 25
SH: 20, 21.

Figure 32 Members of the group examine the granite–Malmsebury shales contact on the Cape Town foreshore.

Appendix 1: Bird list (117 species)

(names and taxonomic order from Ian Sinclair, Phil Hockey and Warwick Tarboton 2002 *Sasol Birds of Southern Africa* (3 edn). Cape Town: Struik

Ostrich *Struthio camelus*
African (Jackass) Penguin *Spheniscus demersus*
Cape Gannet *Morus capensis*
White-breasted Cormorant *Phalacrocorax lucidus*
Cape Cormorant *Phalacrocorax capensis*
Reed Cormorant *Phalacrocorax africanus*
Little Egret *Egretta garzetta*
Cattle Egret *Bubulcus ibis*
Black Stork *Ciconia nigra*
African Sacred Ibis *Threskiornis aethiopicus*
Hadeda Ibis *Bostrychia hagedash*
African Spoonbill *Platalea alba*
Greater Flamingo *Phoenicopterus ruber*
Egyptian Goose *Alopochen aegyptiaca*
Spur-winged Goose *Plectropterus gambensis*
Secretarybird *Sagittarius serpentarius*
Cape Vulture *Gyps coprotheres*
White-backed Vulture *Gyps africanus*
Lappet-faced Vulture *Torgos tracheliotus*
Black-shouldered Kite *Elanus caeruleus*
Verreaux's (Black) Eagle *Aquila verreauxii*
Tawny Eagle *Aquila rapax*
Booted Eagle *Aquila pennatus*
Martial Eagle *Polemaetus bellicosus*
Black-breasted Snake Eagle *Circaetus pectoralis*
Bateleur *Terathopius ecaudatus*
Jackal Buzzard *Buteo rufofuscus*
Rufous-chested Sparrowhawk *Accipiter rufiventris*
Gabar Goshawk *Melierax gabar*
Southern Pale Chanting Goshawk *Melierax canorus*
Lanner Falcon *Falco biarmicus*
Rock Kestrel *Falco [tinnunculus] rupicolis*
Greater Kestrel *Falco rupicoloides*
Cape Francolin *Peliperdix sephaena*
Helmeted Guineafowl *Numida meleagris*
Red-knobbed Coot *Fulica cristata*
Kori Bustard *Ardeotis kori*
Ludwig's Bustard *Neotis ludwigii*
Karoo Korhaan *Eupodotis vigorsii*
Ruppell's Korhaan *Eupodotis ruepellii*
Northern Black Korhaan *Eupodotis afraoides*
African Black Oystercatcher *Haematopus moquini*
White-fronted Plover *Charadrius marginatus*
Three-banded Plover *Charadrius tricollaris*
Crowned Lapwing (Plover) *Vanellus coronatus*
Blacksmith Lapwing (Plover) *Vanellus armatus*
Burchell's Courser *Cursorius rufus*
Hartlaub's Gull *Larus hartlaubii*
Cape (Kelp) Gull) *Larus vetula*
Swift Tern *Sterna bergii*
Namaqua Sandgrouse *Pterocles namaqua*
Double-banded Sandgrouse *Pterocles bicinctus*
Feral Pigeon *Columba livia*
Red-eyed Dove *Streptopelia semitorquata*
Cape Turtle-dove *Streptopelia capicola*
Laughing Dove *Streptopelia senegalensis*
Namaqua Dove *Oena capensis*
Grey Go-away Bird *Corythaixoides concolor*
Burchell's(?) Coucal *Centropus burchelli*
Spotted Eagle-owl *Bubo africanus*
Giant Eagle-owl *Bubo lacteus*
Little Swift *Apus affinis*
Alpine Swift *Tachymarptis melba*
African Palm-swift *Cypsiurus parvus*
White-backed Mousebird *Colius colius*
Red-faced Mousebird *Urocolius indicus*
Pied Kingfisher *Ceryle rudis*
Lilac-breasted Roller *Coracias caudatus*
Southern Yellow-billed Hornbill *Tockus leucomelas*
Acacia Pied Barbet *Tricholaema leucomelas*
Crested Barbet *Trachyphonus vaillantii*
Golden-tailed Woodpecker *Campethera abingoni*
Grey-backed Sparrowlark *Eremopterix verticalis*
Rock Martin*Hirundo fuligula*
Fork-tailed Drongo *Dicrurus adsimilis*
Cape Crow *Corvus capensis*
Pied Crow *Corvus albus*
House Crow *Corvus splendens*
African Red-eyed Bulbul *Pycnonotus nigricans*
Olive Thrush *Turdus olivaceus*
Mountain Wheatear (Chat) *Oenanthe monticola*
Familiar Chat *Cercomela familiaris*
Sickle-winged Chat *Cercomela sinuata*
Anteating Chat *Myrmecocichla formicivora*
Cape Robin *Cossypha caffra*
Bar-throated Apalis *Apalis thoracica*
Black-chested Prinia *Prinia flavicans*
Karoo (Spotted) Prinia *Prinia maculosa*
Fiscal Flycatcher *Sigelus silens*
African Pied Wagtail *Motacilla aguimp*
Cape Wagtail *Motacilla capensis*
Common Fiscal Shrike *Lanius collaris*
Crimson-breasted Shrike *Laniarius atrococcineus*
Brubru *Nilaus afer*
Bokmakierie *Telophorus zeylonus*
Common Starling *Sturnus vulgaris*
Burchell's Starling *Lamprotornis australis*
Cape Glossy Starling *Lamprotornis nitens*
Red-winged Starling *Onychognathus morio*
Pale-winged Starling *Onychognathus nabouroup*
Cape Sugarbird *Promerops cafer*
Malachite Sunbird *Nectarinia famosa*
Orange-breasted Sunbird *Anthobaphes violacea*
Marico Sunbird *Cinnyris mariquensis*
Southern Double-collared Sunbird *Cinnyris afer*
Dusky Sunbird *Cinnyris fuscus*
Cape White-eye *Zosterops capensis*
Orange River White-eye *Zosterops pallidus*
Sociable Weaver *Philetairus socius*
House Sparrow *Passer domesticus*
Cape Sparrow *Passer melanurus*
Southern Grey-headed Sparrow *Passer diffusus*
Scaly-feathered Finch *Sporopipes squamifrons*
Southern Masked Weaver *Ploceus velatus*
Black-faced Waxbill *Estrilda erythronotus*
Red-headed Finch *Amadina erythrocephala*
Yellow Canary *Serinus flaviventris*

Appendix 2: Mammal list (30 species)

(names and taxonomic order from Jonathan Kingdon *The Kingdon Pocket Guide to African Mammals*. London: A & C Black)

Chacma Baboon *Papio ursinus*
Vervet Monkey *Cercopithecus pygerythrus*
South African Ground Squirrel *Geosciurus inauris*
Spring Hare *Pedetes capensis*
Four-striped Grass Mouse *Rhabdomys pumilio*
Black-backed Jackal *Canis mesomelas*
Cape Fox *Vulpes chama*
Bat-eared Fox *Otocyon megalotis*
Suricate (Meerkat) *Suricata suricata*
Small Grey Mongoose *Herpestes pulverulenta*
Yellow Mongoose *Cynictis penicillata*
Common (Spotted) Genet *Genetta genetta*
(Southern African) Wild Cat *Felis silvestris cafra*
Cheetah *Acinonyx jubatus*
Lion *Panthera leo*
Cape Rock Hyrax (Dassie) *Procavia capensis*
Burchell's Zebra *Equus quagga burchelli*
Mountain Zebra *Equus zebra*
Common Warthog *Phacochoerus africanus*
Greater Kudu *Tragelaphus strepsiceros*
Steinbuck (Steenbok) *Raphicerus campestris*
Klipspringer *Oreotragus oreotragus*
Springbok *Antidorcas marsupialis*
Khama (Red) Hartebeest *Alcephalus bucephalus caama*
Blue Wildebeest (Brindled Gnu) *Connochaetes taurinus*
Southern Oryx (Gemsbok) *Oryx gazelle*
Cape Fur Seal *Arctocephalus pusillus*
Humpback Whale *Megaptera novaeangliae*
Bryde's Whale *Balaenoptera edeni*
unidentified **Dolphin** sp.

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Book review

McCann, Tom (ed.) 2008 *The Geology of Central Europe, Vol. 1: Precambrian and Palaeozoic*. Bath: The Geological Society (ISBN 978-1-86239-246-5, paperback, 850pp; £45)

This extensive survey of current geological knowledge of the formation of Central Europe from Belgium to the Carpathians, and from the Baltic Shield to the Massif Central of France, has been compiled by more than 200 authors. The first volume has chapters devoted to the Precambrian, Cambrian, Ordovician, Silurian, Devonian, Carboniferous and Permian periods, interspersed with chapters covering the major periods or tectonic activity: Cadomian, Caledonian and Variscan. A final chapter covers Palaeozoic Magmatism.

The main thrust of this volume is on the tectonic control of sedimentary and volcanic activity, with very little information being provided on biological input. The trend towards using microfossil assemblages to differentiate formations is mentioned, but for details of these assemblages you are referred to published papers.

With so many authors, it is perhaps inevitable that there is a significant amount of overlap. The coverage of any particular period in any region is sparse. Authors have not restricted themselves solely to the period under discussion, with the result that information on different periods is scattered among the chapters. It was surprising that the Devonian chapter is only a quarter of the length of the Carboniferous chapter, which contained almost as much information on the Devonian as the chapter devoted to the subject.

Only passing reference is made to the UK, mostly when discussing the accretion of Avalonia during the Caledonian orogeny and the UK extension of the Permian basin under the North Sea. There is, however, an interesting section on the Channel Islands, where the 2.2Ga age of the oldest rocks on Guernsey set me wanting to revisit the island in the near future — ideally with an OU field trip.

This is a heavyweight book in every sense of the word. The 850 large pages, weighing 2.2kg, are each printed with more than 100 lines in small print, written for the benefit of experts rather than for beginners. The text is accompanied by many informative black and white illustrations and there are thousands of references, many of them to papers published in the 21st century. As a source book for the latest thinking on the tectonic history of central Europe it is excellent, but do not expect to find enough information about any area to plan a geological trip.

— Martin Bryan

McCann, Tom (ed.) 2008 *The Geology of Central Europe, Vol. 2: Mesozoic and Cenozoic*. London: The Geological Society (ISBN 978 1 86239 264 9, hardback £95; 978 1 86239 265-6, paperback £45; 738pp)

Do not think that you will be able to slip this into your knapsack on that walking trip of the Carpathians; you might even think twice about packing it for the cruise up the Danube and down the Rhine, even though the area covered stretches from Slovakia to the Netherlands. The hardback weighs in at 2.47kg; even the paperback is 2.25kg. And that is only volume 2. It is, as the GeolSoc says: "a key reference work suitable not only for libraries across the world, but of interest to all researchers, teachers and students of European Geology". This volume covers the period beginning with the destruction of Pangaea and ending with the formation of the Alps and Carpathians and the subsequent Ice Ages. Nine chapters cover the Triassic, Jurassic, Cretaceous, Permian to Cretaceous tectonics, Palaeogene and Neogene, Alpine tectonics of the Alps and Western Carpathians, Alpine tectonics north of the Alps, the Quaternary, and fossil fuels, ore and industrial minerals. A mineral and energy resources map at 1:2 500 000 is provided on an attached CD, covering the area from Belgrade to the North Sea Central Graben and from the Rhone delta to Lithuania.

Each chapter is written by several authors — more than 200 contributed to the two volumes — and ends with several pages of references. As the publishers say: "Individual chapters outline the evolution of the region divided into a variety of sections, which include overviews of the stratigraphic framework, climate, sea-level variations, palaeogeography and magmatic activity. These are followed by more detailed descriptions of the Central European succession, covering the main basins and magmatic provinces."

This summary interestingly shows current geological priorities. The chapters are in fact differently divided; for example the Triassic into an introduction, the Permian-Triassic boundary, climate evolution in the Tethys area and its controls, sea-level changes and cyclostratigraphy, general tectonic setting, palaeomagnetism, Germanic realm sedimentary basins, Tethyan realm stratigraphy and basin development, palaeontology, and summary; while the Jurassic and Cretaceous chapters lack separate sections on palaeomagnetism and palaeontology. The index covers both volumes – I do not know if it is in Vol. 1 also, the introduction and overview is only there. The numerous figures are all in black and white, but extremely clear.

This is a notable contribution to the GeolSoc's remarkable series of authoritative volumes on areas as diverse as the South Caspian to Central Iran basins, the Southern California Continental Borderland, and Northern Tanzania.

— Philip Clark, MA (Oxon), BSc Hons (Open)

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Mount Snowdon and Scafell Pike: a comparison of the geology and present-day surface features

Chris Popham

About 500Ma ago during the Ordovician period, the part of the surface of the earth that was to become England and Wales was forming in the depths of the Iapetus Ocean.

Gradually, during the late Ordovician (450Ma) the ocean basin began to close as ocean floor was subducted under a neighbouring plate resulting in the formation of an island arc of volcanoes close to the subduction zone. Massive quantities of ash and lava were ejected, which settled on the ocean floor and contributed to the formation of the islands. By 400Ma, at the close of the Silurian period, the subduction process brought two land masses together during the Caledonian orogeny, which built a mountain range over what is now the Lake District and Snowdonia. There then followed a long period of erosion and submergence before once again a continental collision during the late Carboniferous period (280Ma) caused another mountain-building event — the Variscan orogeny — which again lifted up the Lake District and Snowdonia.

Over the last 1.4Ma glacial events have exposed much of the underlying geology as well as creating distinctive scenery. Mount Snowdon (Yr Wyddfa in Welsh; elevation 1085m), the highest mountain in Wales, and Scafell Pike (elevation 978m), the highest mountain in England, provide two locations at which substantial sequences of the geology can be observed.

Mount Snowdon

The route

We climbed Yr Wyddfa on 15 August 2008 by way of the Miner's Track from Pen-y-pass and descended on the Pyg Track. This 'circular' walk is approximately 7.5 miles and took about six hours at a family walking pace. There is a very small car park at Pen-y-pass (British national grid reference (BNG) SH647556), but this is usually full early in the morning. The best way to reach this start point is to make use of the local bus services from either Betws-y-Coed or the bus stop in the large car park in Nant Peris. These buses stop in the Pen-y-pass car park and during the summer there is a chance that you will get to travel on one of the open-top buses, which is a great way to take in the scenery. On route there is a good view of the glacial Llanberis Pass, and on the Betws-y-Coed route look out for prominent *roche moutonnée* beside the open moorland road.

The lower section of the Miner's Track has only a shallow gradient and follows the contours of the hillside as far as the Llyn Llydaw Reservoir. It is well made, topped with crushed slaty gravel and certainly fit for a sturdy 4 × 4 all the way to the ruins of Britannia Mine on the far shoreline. To the first turn the track crosses underlying acid tuff, at the turn it crosses a corner of a dolerite intrusion before crossing back on to the tuffs. Unfortunately, however, most of this is hidden beneath the surface soils and vegetation, and the gently sloping moraine dam that holds back the reservoir.

The view, meanwhile, is dominated by the high, sheer wall of Y Lliwedd. This is the headwall of a cirque formed during the recent glacial periods and is a mass of sharp, broken, volcanic rocks, rising almost directly from the shore of the reservoir.

As the track rounds the corner at the foot of the reservoir and crosses a shallow causeway a prominently banded rock face is displayed directly ahead. The lower section has a somewhat rounded profile cut by several bright bands of white quartz revealing the 'acid' nature of the rock. Above this is Crib Coch, another almost vertical rough mass a mirror for that seen on the opposite side of the reservoir.

Snowden's geology

The volcanic rocks that form Snowdon were laid down on an eroded basement of late Cambrian and early Ordovician rocks. They are a mix of ash fall, pyroclastic and intrusive rocks. It seems likely these were erupted from a string of island volcanoes standing in shallow water, as in some places the beds apparently form a continuous succession indicating deposition on land, whereas in other places they are interbedded with fossiliferous marine sedimentary beds containing graptolites and trilobites. It also appears that as time went on the principal focus of activity moved in a north-easterly direction. As a consequence of these factors it seems that the vent that put out the volcanic rocks of Snowdon must be close by, although the exact location is unknown.

Beyond Britannia Mine (also known as Snowdon Mine or Britannia Copper Mine; active from about 1800 to 1916) the track climbs quite steeply but again the surface has been made up only this time with large slabs of stone. Here a note of caution must be added as these stones have for the most part been delivered in 'Helibags'; extra reinforced versions of the one-ton dumpy bags in which sand and gravel are delivered by builders merchants. Piles of these bags line parts of the routes allowing the contents to be inspected and from which it becomes immediately apparent that the contents have come from far and wide.

The track reaches the higher Glaslyn lake (Fig. 1, *overleaf*) through a narrow constriction formed by opposing arms of rock. This is a classic cirque with the peak of Snowdon forming the backdrop. In Snowdonia the majority of the well-formed glacial formations are on the shaded north face of the mountains. From these locations the glaciers flowed northward until they encountered the southward flowing sea ice coming down from the Lake District and beyond. The south-flowing ice diverged, some if it passing on down the Irish sea, while the remainder was forced inland to move down the low ground along the Welsh–English boarder. Sufficient evidence of this comes from the erratic boulders found in the boarder regions, which were dropped by the retreating ice and whose origins can be traced back to the Lake District (e.g. pieces of Eskdale granite).

The Miner's track again takes a level path along the Glaslyn shore, passing a number of ruined mine buildings and adits, the most prominent of which is marked by a large mound of orange-coloured spoil, although this was only a late trial drive.

From here the track begins to climb very steeply, in places the uneven steps become almost a scramble over pale worn rocks and loose stones before joining the Pyg Track. This waypoint is marked by a small monolith thankfully done in native stone and coincidentally marking the point where the acid tuffs become overlaid by basic lavas and tuffs. This is also a perfect vantage

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Figure 1 Glaslyn lake and the Snowdon summit.

point from which to look down over the lakes below and the massive vertical wall of Y Lliwedd.

Beyond this the path is well paved and makes a steep zigzag across the mountainside before it reaches the arête that runs westward from the peak towards Llanberis. The path then follows the line of the railway to the summit station. This final section has been so worked over by the building of the railway and a succession of summit hotels and cafes that any natural geology is extremely hard to find. At the time of writing a new replacement cafe and station is being built and as part of this redevelopment a flight of steps has been built from the railway platform to the actual summit, all in white granite that could well have come from Merrivale Quarry on Dartmoor!

The glacial view

The view from the summit is undoubtedly magnificent. The mountains stretch out to the North Wales coast, though seemingly with their backs to this viewpoint. To see the best view of what the glacial period left it is necessary to look southward whereupon it appears the landscape is made of a succession of vertical grey walls, each folded around a small lake where glaciers were once born. It is also apparent that the main structure of Snowdon is one of five arms of high ground separated by valleys forming a radial drainage pattern initiated from this high ground. Yet it also seems slightly ironic that this present-day high point actually sits atop the lowest part of the Snowdon syncline and further, that the occurrence of marine fossils in some of the summit beds clearly shows that deposition took place on a seabed.

The initial descent follows the path already described as far as the monolith. The Pyg Track then takes a route that hugs the hillside, descending only gently. However, the almost unrelenting descent over many rough steps is in some ways more wearing than the route already taken up the Miner's Track. Once the first shoulder reaching down from Crib Coch to the outflow of Glaslyn has been rounded it is possible to gain a fuller appreciation of the glacial nature of the landscape.

It is thought that the higher peaks in Snowdonia were not covered by the ice sheet during the most recent glacial period; rather that the rocky peaks remained projecting above the ice as 'nantucks', worked on by the agents of freeze thaw and shattering. As the climate became milder snow and ice would have lingered longest on the north facing mountainsides where cirques such as that occupied by Glaslyn developed. Ice spilling from here undoubtedly worked on the lower slopes around Llyn Llydaw, producing the softer, rounded outlines that are clearly seen. The higher slopes became rough frost shattered faces, a process that continues to the present day, constantly adding to the small screes below Crib Coch on the western hillside. And it is from this vantage point that the moraine dam at the foot of Llyn Llydaw can be seen and appreciated best.

There is also an underlying reason for the rounded western hillside in the form of a large intrusion of fine-grained rhyolite (Fig. 2, *opposite*). This is well exposed alongside the Pyg Track in several places above Llyn Llydaw and the jointing, probably the result of contraction during cooling, gives the overall appearance of a domed structure clearly lacking the layered characteristics of the tuffs seen elsewhere.

The tuffs reappear as a prominent rock face above the track where it climbs over the north-western ridge leaving the Llyn Llydaw valley. The face is somewhat undercut, possibly where there is a softer layer, but clearly displaying the fine bedding better than at any other place on the walk (Fig. 3, *opposite*).

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Figure 2 Intrusive fine-grained ryolite on the Pyg Track, above Llyn Llydaw, Snowdon.

On the northern side of the ridge the walking underfoot is some of the most difficult of the whole circuit. The ground is littered with large scree blocks and the path twists around these rock outcrops and makes many short, near-vertical descents. This may in part be due to the north-facing aspect, which may have held a small snow field until quite late in the glacial period. This would have promoted frost shattering, and may in part be due to the action of the glacier that once flowed down the Llanberis Pass from this point, plucking rocks from the hillside. Both of these processes were undoubtedly favoured by the numerous rhyolite intrusions in this hillside and by a number of minor faults, which in fact account for the majority of the faulting seen on this face of the mountain. Both these factors will have adversely affected the integrity of the hillside.

As has been mentioned, it is worthwhile stopping and looking behind on this short section for the uninterrupted view down the length of the Llanberis Pass. This exhibits the textbook U shape profile of a glacier-carved valley, and the ribbon lakes of Llyn Peris and Llyn Padarn can be seen in the distance.

Figure 3 Layered tuffs exposed above the Pyg Track on Llyn Llydaw, Snowdon.

Scafell Pike

We climbed Scfaell Pike on 22 August 2008 by way of the Brown Tongue and Hollow Stones route from Wasdale Head National Trust camp site, where there is also a public car park (BNG NY183074). Descent was by the Piers Gill and Wasdale Head Inn route, making this route, like that on Snowdon, a 'circular' walk of approximately 7.5 miles taking about eight hours. Although the summit of Scafell Pike is 100m lower than that of Snowdon, the amount of ascent is greater, as the starting elevation from Wasdale head is only 80m above sea level, whereas Pen-y-pass is at 360m above sea level.

The surrounding glacial landscape

At first the path follows Lingmell Gill up valley in a steep, rounded, grassy hillside, which reveals little of the underlying geology. In the accompanying succession chart, at the beginning of the ascent, series 2 comprises narrow horizons of quartz-feldspar granite — marked FG in the key. This is actually the same band of rock that has been faulted and thrown approximately 10m vertically in such a way that the path, traversing the hillside very slightly, just passes over the separated ends of the band. As the path follows the course of the beck it should be possible to see this granite exposed in the stream bed.

As height is gained the full glacial nature of Wasdale below becomes apparent. Wast Water is possibly the finest glacially over-deepened lake in England or Wales. The lake surface is 80m above sea level but the bottom is 20m below sea level — the deepest lake in England. At the head end, grassy deltas have formed on material deposited by Lingmell Beck, which drains from the head of the U-shaped valley below Great Gable. On the far side of the lake the high masses of Yewbarrow, Long Crag and Buckbarrow can be seen, separated by hanging valleys farther cut down by river action. The extensive screes that tumble steeply from Illgill Head and Whin Rigg to the lake shore and on down to the lake bottom will already have been seen on the drive to the car park. The foot of the lake is dammed by an extensive moraine. Beyond that, the plain stretches out to the sea, with the Isle of Man on the horizon.

Once again, as on Snowdon, the surface of this section of the path has been made up with large stones delivered in helibags.

At the head of Brown Tongue the path emerges onto the area known as Hollow Stones, although the stones are not, of course, hollow and the name Stone Hollow may have been more appropriate. Here the geology of the mountain is displayed full

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on. Hollow Stones is in many ways a cirque, as is Glaslyn on Snowdon, but here there is no lake or tarn. The hollow has not been deepened sufficiently to hold a tarn but the ground is also very dry underfoot, suggesting that there is good drainage. The stones are undoubtedly a moraine residue left after the fine soil has been carried away by water. The blocks are angular and anything up to cubes 3m on each side. However, the most instantly striking feature is the strong layering seen in the majority of the blocks. These are tuffs just like those seen on Snowdon and at both locations deposition may have taken place at a similar point in time.

The Scafell tuffs are part of the Borrowdale Volcanic Group (BVG), which account for most of the rocks exposed in a band across the middle third of the Lake District, forming a unit up to 4000m thick. The BVG comprises lavas, pyroclastic deposits and ash fall layers with agglomerates, lava droplets (lapilli) and intrusions (Fig. 4).

Figure 4 Agglomerate in Scafell BVG lava.

In contrast to Snowdonia, deposition in the vicinity of Scafell appears to have occurred mostly on land, as there is an absence of fossils and only very rare sedimentary beds. However, ripple marks in some of the beds clearly indicate that transient lakes or periods of marine submergence must have occurred (Fig. 5). The tuffs may be coarse or very fine and in places these fine deposits have been altered to form excellent slates as, for example, at Honister. Around Scafell the tuffs are mostly of a grey-green colour, though in places stained with haematite and iron oxides. Pyrite is locally common and some of the lavas contain microscopic dark red garnets.

The peak of the mountain can now be seen to be in two parts Scafell Pike to the left (east) and Scafell, just 14m lower than its neighbour, to the right, with the ridge of Mickledore separating them. The whole peak forms a near semi-circular wall to the south enclosing Hollow Stones.

From here, where the pathway forks, take the left-hand route, which crosses Hollow Stones and then zigzags up a well made path (made incidentally by a mechanical digger that was brought up in 11 parts by helicopter and assembled on site) onto Lingmell Col before turning sharply south and climbing steeply up to the level platform below Scafell Pike.

Bedding

It is at this turn that the bedding is prominently displayed. In the elbow of the turn there is a thick (almost 1.5m) bed of coarse material with lapilli up to the size of peas; and above this *c*. 1m of beds with thicknesses from a few millimetres to tens of millimetres (Fig. 6, *opposite top*). The upper surface of this deposit is littered with broken blocks, but enough of these blocks are clearly *in situ* to show that the beds dip at *c.* 20 degrees to just south of due east. The surface of the rocks has weathered up to 3mm deep to a pale orange colour, below which the green-grey, very fine-grained texture is apparent. In addition some of these tuffs have been welded by heat and hardened to such a degree that when broken they shatter almost like flints.

This vantage point also gives another magnificent view of Wast Water and over the glacier-rounded crests of Illgill Head (610m) and Whin Rigg (535m), to the coast.

Once again the path climbs steeply in short zigzags, and although not made up in any way the larger rocks have been moved aside leaving a surface of rounded, pale, dusty foot-worn pebbles. Some of the rocks warrant closer inspection as among them can be found pieces of agglomerate where angular rock fragments, some of them clearly bedded, have become welded together in a fine green-grey ash matrix.

It is said that the summit of Scafell Pike is one of the finest frost-shattered boulder fields in the country and also that it stood above the glacial ice sheet as did Snowdon. However, this is perhaps an oversimplified view, because the summit appears to have two plateau tiers before the final summit pyramid of broken rocks. These tiers possibly represent the heights of successive ice sheets, although this pattern is not repeated in the adjacent peak of Scafell, which rises steeply to a simple point.

From the summit, as with Snowdon, the radial drainage pattern of the Lake District is evident, although on Scafell Pike this is emphasised by the numerous ribbon lakes. The summit-top boulder fields extend to the nearby summits and merge into the craggy tops of mountains formed from the hard BVG rocks stretching to the eastern horizon of Blencathra and Helvellyn, also formed of BVG rocks.

Figure 5 Ripple marks in BVG volcanic beds.

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Figure 6 Coarse and fine bedding on Sacfell.

North-east is the rounded summit of Skiddaw, formed of softer slates. To the south-east are the lower rounded profiles of hills fashioned from the Silurian sandstones and grits surrounding Windermere. Equally dramatic is the view to the south-west over the U-shaped Eskdale Valley, the rough mass of Harter Fell cut by a prominent hanging valley, and beyond, the coastal plain.

Lava flows, crumpling and ripple marks

The initial descent retraced the route as far as the elbow at Lingmell Col, then turned eastward on a much less trodden path called the Sty Head or Corridor route. This is a completely unmade path winding down between numerous rock outcrops, but with the advantage of more varied features.

Again the rocks are highly layered, but in one exposure the even layers are suddenly disrupted by a band in which folding and crumpling has occurred. This may be a lava flow, as those in the BVG are reported to show a great deal of fragment incorporation or a slump in material that accumulated on a steep incline (Fig. 7). A little farther down the path is a large exposure with very clear ripple marks, the ridges *c.* 80mm apart, as fresh as if they had just been formed by a receding tide. Within a very short distance the path descends a narrow cutting to bring it close to level with the head of Piers Gill and here the rocks are much stained with a surface coating of purple-red haematite, obscuring the fact that some are fine-grained intrusive types.

Peering into the gill

Piers Gill is a deep dog-legged gorge that carries the Lingmell Beck around the back of Lingmell Crag. It is worth taking this little-used pathway, as it affords great views into the gorge and yields some other points of interest. (A note of caution, however: at one point it is necessary to climb down a 10m high, near vertical rock face; although it has plenty of hand- and footholds it requires a good deal of self confidence.)

For 100m the footpath is 'level' and then drops quite suddenly. Here the loose surface pieces of tuff are intermingled with a pale, fine-grained intrusive rock, in a form akin to the pale elvan dykes seen cutting Dartmoor granite. This intrusion is from a narrow vertical dyke beside the path. As the path turns across the hillside another series of intrusions is crossed, possibly representing a succession of events, for their compositions vary from pale, fine-grained, through light pink with substantial phenocrysts, to dark basaltic. These appear at the point in the path where there is the above-mentioned steep 10m descent, and may be related to the Eskdale granite.

Eskdale granite

Eskdale granite forms a northward-pointing finger in the Eskdale valley as far as Beckfoot and Boot. There it has been quarried and may have contributed to the emplacement of the iron ores in the adjacent BVG rocks, mined in Nab Scar Mine above Boot.

Figure 7 Highly crumpled and folded layers on Scafell.

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However, Eskdale is only a fragment of a much more substantial laccolith that extends west and south taking in the foot of Wast Water. An isolated intrusion has also been mapped above Wasdale Head. The dry-stone walls of Wasdale are also largely built of rounded granite blocks, which must account for a huge volume, much possibly excavated from the depths of Wast Water. If this is the case then it may be that the laccolith extends clear under Lingmell accounting for the exposure in Wasdale Head and the intrusions around Piers Gill.

The Eskdale granite is white to mid-pink in colour and shows considerable variation in structure. Around Blea Tarn (BNG NY167010) above Beckfoot, close to the junction with the BVG, it is fine grained, as perhaps would be expected if it cooled quickly on contact. At Rough Crag (BNG SD161977), south of Eskdale, it is coarse and white; while at Water Crag (BNG SD153974), little more than 0.5km farther east it is fine grained and pink. But here an unusual junction between the granite and basaltic andesite lava is clearly exposed in the Crag. An exposure of Eskdale granite in a small, weathered gash in the hillside above the foot of Wast Water (BNG NY144034) is coarse and pink. Given this variety of colours and structure it is not unreasonable to surmise that the intrusions around Piers Gill could be associated with phases of Eskdale origin.

The Eskdale granite forms the valley floor where the path curves in a long arc following the Lingmell Beck. The aquamarine colour of the pools strikes a dramatic contrast with the 'white' boulders in the stream bed. When broken open these rocks are found to be of the fine-grained, grey-green flinty material similar to that higher up the mountain. The whiteness is owing to powdering of the surface and it is probably fine rock powder in the water that gives it the blue colour as do clay particles in the lakes of clay pits. On closer inspection some of the pebbles reveal not only flecks of pyrite but also red-brown garnets.

At Wasdale Head the path passes the doors of the Wasdale Head Inn and Brewery (the Great Gable ale is a little insipid but the Illgill Head is well worth sampling), takes briefly to the road and then rejoins the boulder-scattered bed of the Lingmell Beck as far as the car park. Although not immediately apparent from the ground this is a good example of a braided river bed, the form of which can be appreciated in postcard pictures taken from the summit of Great Gable at the head of the valley (Fig. 8, *right and opposite*).

Conclusion

In conclusion, the mountainous areas that include Scafell Pike and Snowdon have striking similarities. Both were formed in the late Ordovician period during the Caledonia orogeny, as a result of subduction and the closure of the Iapetus Ocean. Both are comprised in the main of volcanic tuffs, pyroclasts, lavas and intrusive rocks, which show evidence of deposition both on land and in shallow lakes or seas. The hardness of these rocks and the subsequent metamorphism during burial and erosion during uplift had a direct impact on the appearance of both mountains, giving them a rough, craggy appearance around their summits. Both are centered at the hub of radial drainage patterns, initially cut by rivers but more recently re-sculpted by glacial action, which smoothed the outlines of the lower flanks. In contrast however, the rocks of Scafell Pike are in the main grey-green and more altered (hardened), than those of Snowdon, which are darker and softer.

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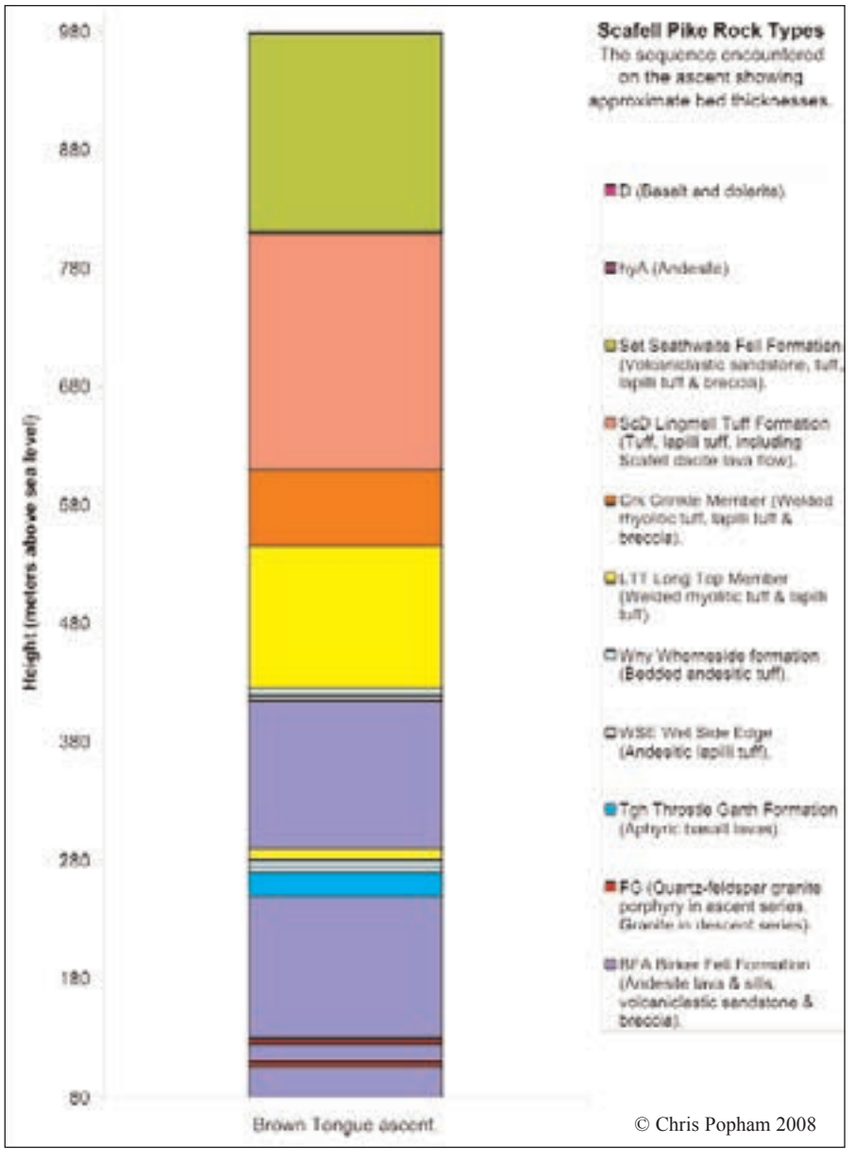
Scafell Pike Rock Types
The sequence encountered on the ascent showing approximate bed thicknesses.
Height (meters above sea level)
980
880
780
680
580
480
380
280
180
80
D (Basalt and dolerite)
hyA (Andesite)
Set Seathwaite Fell Formation (Volcaniclastic sandstone, tuff, lapilli tuff & breccia).
ScD Lingmell Tuff Formation (Tuff, lapilli tuff, including Scafell dacite lava flow).
Crk Corridor Member (Welded rhyolitic tuff, lapilli tuff & breccia).
LTT Long Top Member (Welded rhyolitic tuff & lapilli tuff)
Wny Whorneside formation (Bedded andesitic tuff).
WSE Wet Side Edge (Andesitic lapilli tuff).
Tgh Thrasbe Garth Formation (Aphyric basalt lavas)
FG (Quartz-feldspar granite porphyry in ascent series. Granite in descent series).
BFA Birker Fell Formation (Andesite lava & sills, volcaniclastic sandstone & breccia).
Brown Tongue ascent
© Chris Popham 2008

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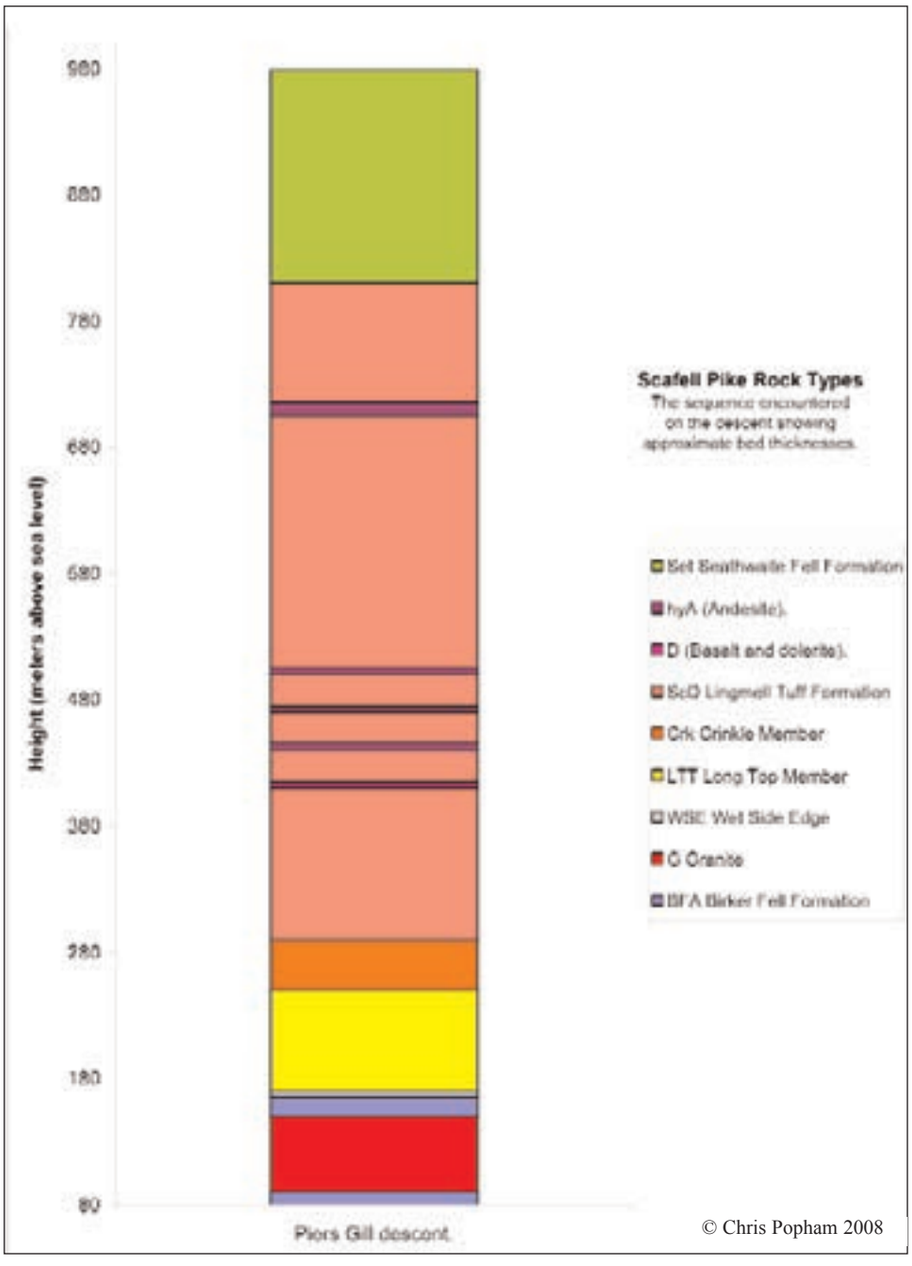
The author

Chris Popham is currently Branch Organiser of the OUGS South West Branch.



Geological evolution of the Thames Basin a lecture by Dr Andrew Newell, BGS*

report by Brian Teasdill

This was an exceptionally clear and informative talk about the geology of our home area: the Thames Basin. Dr Newell showed us the main geological formations, explained how they control the geomorphology, and how this has been further shaped by sea level changes and by global climate changes.

The Thames catchment area is defined by all the watercourses that drain into the Thames estuary, including the Medway. This is an area of about 200km by 100km. As explained later, the catchment area has been more extensive in the past.

The sub-Mesozoic basement

The surface geology consists of Jurassic, Cretaceous, Tertiary and Quaternary sediments. These rocks are already well known to most of our members. But we were in for a surprise! The main part of the talk started with new information about the sub-Mesozoic basement.

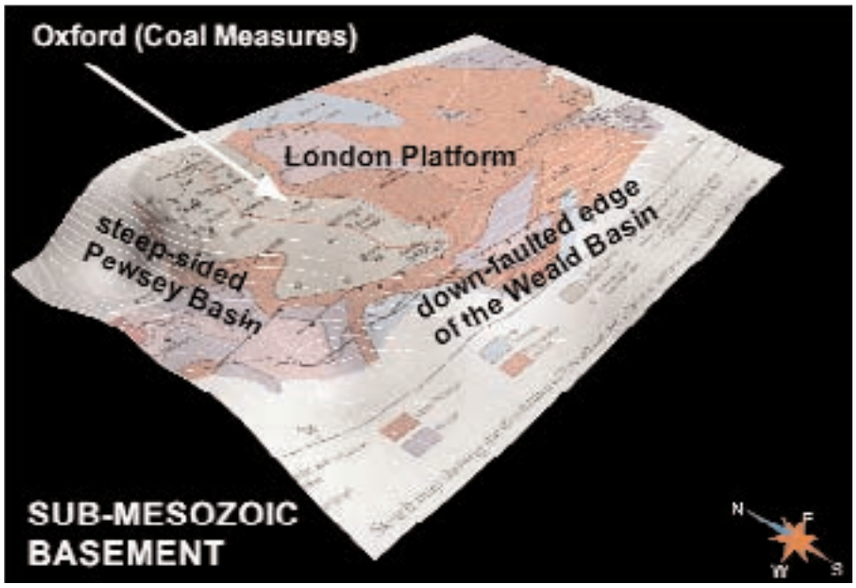


Figure 1 Computer-generated contour diagam of the London Platform.

The basement is the eroded surface of previously folded Silurian, Devonian and Carboniferous sediments. The computer-generated contoured diagram (Fig. 1) shows that most of this basement forms the London Platform, all of which is only a few hundred metres below the surface. A steep faulted step to the south produced the broad Wealden Basin — this part of the basement is about 2,000m below the surface. To the west there is the narrow Pewsey Basin, which goes steeply down to about 1,500m below the surface. The presence and thickness of subsequent deposition in the Mesozoic was much influenced by this underlying profile.

A cross-section along the edge of the Pewsey Basin (Fig. 2) shows that there are coal measures only 300m below Burford and Witney. If it had been discovered in the 19th Century, and if the seams had been a bit better, that part of Oxfordshire probably would have become an industrial wasteland, spoiling the Cotswolds and greatly upsetting the neighbours in the dreaming spires of Oxford! The cross-section also shows that there is some interesting hard rock geology within about 1km of the surface.

In the rest of his talk, Dr Newell showed us the important influences that this ancient basement has on the surface geology — something that most of us had not previously realised.

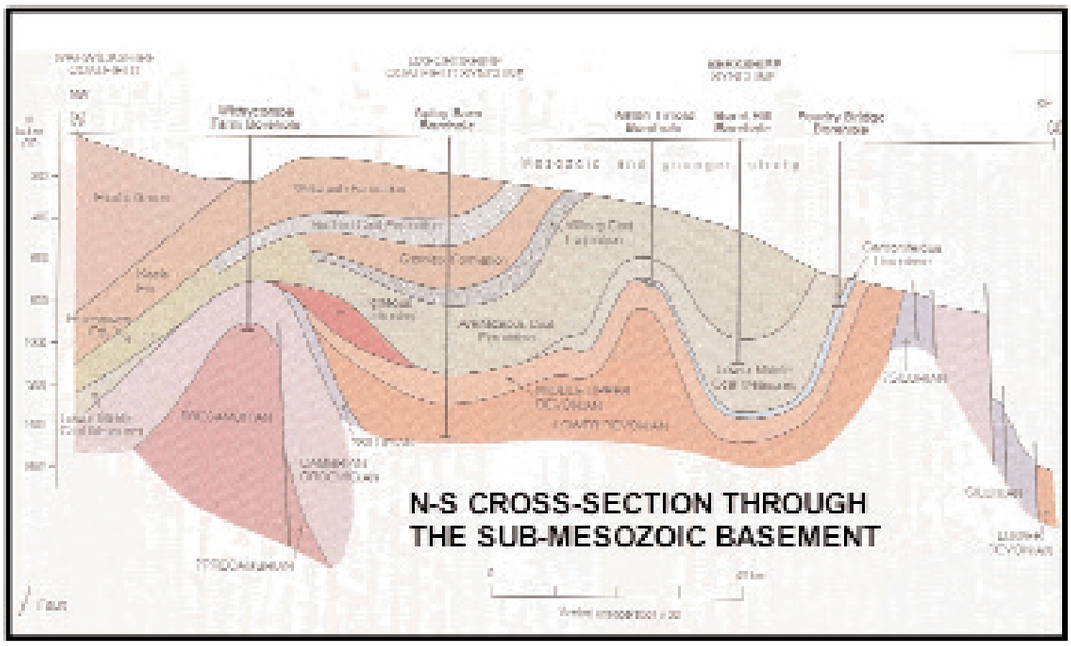


Figure 2 Cross-section of the Pewsey Basin.

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The structure above the basement

The main structure of the surface rocks is a large asymmetrical syncline (Fig. 3).

The whole of Oxfordshire is in the broad northern part of the syncline. It has carbonates and mudstones dipping gently south-eastwards towards the central core of sand and mud in the London area. The southern edge of the syncline is the steeply northward-dipping Chalk that forms the North Downs. The Wealden sands and clays in the south-east just manage to be part of the Thames catchment area. They form part of the adjacent Wealden anticline.

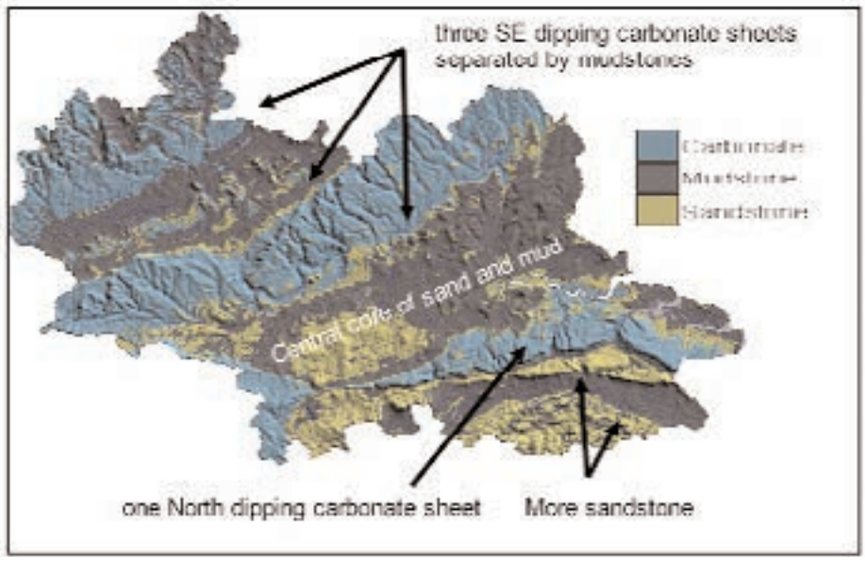
three SE dipping carbonate sheets separated by mudstones
Central core of sand and mud
one North dipping carbonate sheet
More sandstone

Figure 3 The asymmetrical syncline of the Thames Basin structure.

The Cotswold Limestone

The northern headwaters of the Thames are on the Inferior and Great Oolites, which sit directly above the basement unconformity.

The cross-bedding of the ooliths shows that they were formed in strong tidal currents. The beds thin and become more terrestrial from west to east. This is related to the underlying London platform, which was an island in the Jurassic (Fig. 4). Thick-bedded limestones formed offshore (to the west). The onshore areas (to the east) feature lagoonal muds, with roots and footprints.

The pronounced jointing in the limestones has shaped the drainage system of the Cotswold watercourses: comprising the Churn, the Coln, the Leach, the Windrush, the Evenload and the Cherwell). Each flows in a series of 'legs', roughly at right angles.

Above the limestone (and therefore outcropping to the south-east of it) is the Oxford Clay.

The Corallian formation

The Corralian formation was layered over the top of the Oxford Clay, and its present-day outcrop is farther south — it runs across the base of Boars Hill, where the OU Centre is.

The Corallian landscape was diverse: it formed from a patchwork of coral reefs, with channel fills of bioclastic sands and mud. Today its remnants form a narrow ridge between Swindon and Aylesbury, a ridge that forced the Thames to follow the strike in a north-easterly direction before it broke through to flow south via Oxford and the Sandford narrows, and into the Goring gap. Above Corralian formation is the Kimmeridge Clay.

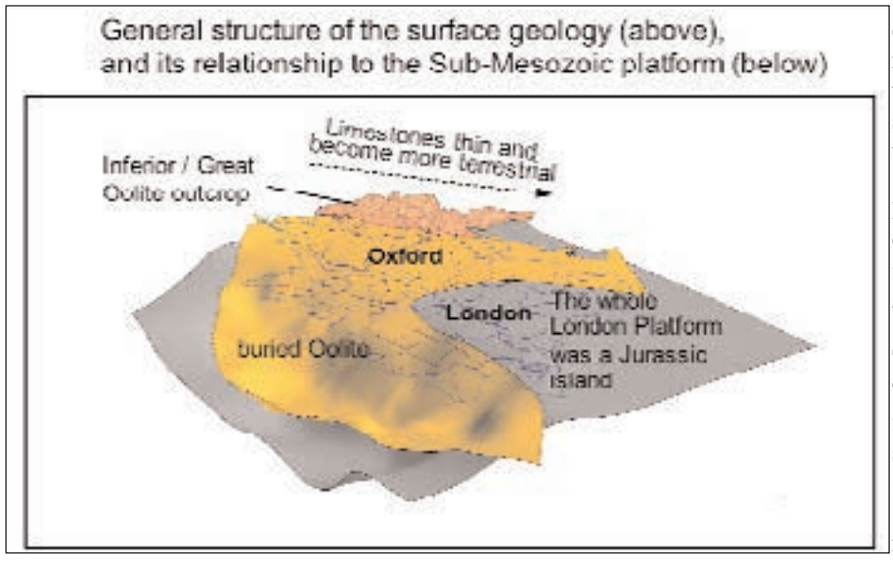
General structure of the surface geology (above),
and its relationship to the Sub-Mesozoic platform (below)
Inferior / Great Oolite outcrop
Limestones thin and become more terrestrial
Oxford
London
The whole London Platform was a Jurassic island
buried Oolite

Figure 4 The relationship between the Jurassic, sub-Mesozoic London Platform and the surface geology.

The Wealden Basin

The early Cretaceous bedding is exposed in the core of the dome-like Weald anticline along the southern side of the Thames Basin. The northern part is made part of the Thames catchment area by four rivers that cut through the Chalk: the Wey, the Mole, the Darent and the Medway).

The central (and oldest) part is the Weald is the Hastings Sands Formation, surrounded by the Weald Clays. These older Wealden layers are absent from the area underlain by the London Platform, caused by the break-up of continents that began in the Jurassic Period.

When the North American plate ripped apart from the Eurasian plate, the crustal extension produced faulting that resulted in (a) uplift of the London Platform and consequent erosion of the Mesozoic sediments on it; and (b) rifting that produced the Wealden Basin, into which erosion of the northern area delivered the succession of thick marine clastics comprising the Hastings Sands and the Wealden Clays.

This extensional regime continued into the Lower Greensand beds above the Wealden Clays. The Greensand outcrop is below and in front of the Chalk escarpments in Oxfordshire and Surrey.

The Chalk

This is a fine-grained, pure limestone, which formed from the deposition of coccoliths and shell fragments in a warm sea of depths between 100 and 300m.

This warm, shallow sea and the Chalk originally extended across the whole of the London Platform, and over the Midlands and perhaps as far as North Wales; but all of the Chalk to the north has been removed by

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subsequent erosion, mainly in the Tertiary sub-Era. As seen on geological maps today, the Chalk has an average thickness of 200m, and forms a continuous 'fence' around the younger strata subsequently deposited on top of it in the present London Basin.

The chalk outcrop width in the northern part is wider, having a uniform dip, which is much less than that in the south of the syncline, which is up to 50º. The thickest layers are in the Farnborough area, where the sub-Mesozoic basement is at greater depth.

The chalk is porous and fractured, which causes the drainage pattern to consist of dry valleys and springs that flow only after prolonged rainfall.

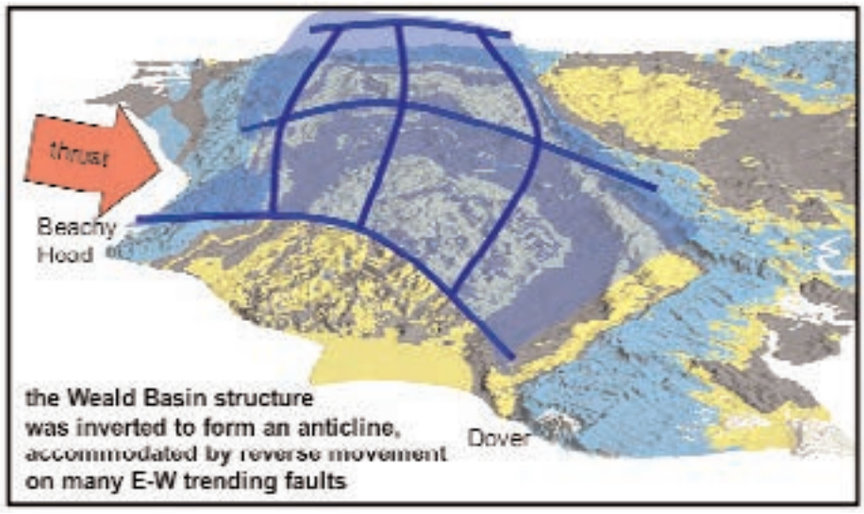

Figure 5 The dome of the Weald created by the northward drift of the African plate.

The Tertiary sub-Era

Above the Cretaceous beds there is a 250Ma time gap, during which there was uplift in the north-west (where Iceland then was), and a regional down-tilting to the south-east of the Cotswolds and the Chilterns, and the Berkshire Downs. The top of the chalk was eroded, producing a karstic surface.

Up to 250m of Paleogene sands and clays were deposited above the Chalk, in tidally influenced marine and coastal plain environments, including the London Clay.

The northward drift of the African plate continued into the Miocene Epoch of the Tertiary, a northward thrust that formed the Pyrenees and the Alps. It also caused compression in England [or 'in the Thames Basin'], squeezing the weak mudstones of the Wealden Basin and forming the dome of the Weald (Fig. 5). This uplift forced a gap in the deposition in the Weald, and also turned much of the London Platform into a basin.

The few surviving deposits from the Neogene Perod at the end of the Tertiary are now at an elevation of about 200m above sea level.

The Quaternary Period

When the Quaternary Period and its major glaciations began, the Thames catchment area had only recently been uplifted from the sea. It — and most other land near by — was probably still buried under a fairly uniform layer of Tertiary sediments.

Sea level continued to drop, owing to the accumulation of many km^3 of water into the ice sheets. At their maximum advances, these ice sheets never got farther south than the northern margins of the Thames catchment area, but the result of their advance was rapid river erosion and mass wasting under periglacial conditions in the Thames Basin. This produced the topography that we see today.

The area was dominated by braided rivers, which deposited gravel. In the interglacial periods meandering rivers deposited silt and sand. Thus the main Quaternary deposits in the Thames catchment area are the river terrace gravels. There is glacial boulder clay in the northern edge of the catchment, in Hertfordshire.

There is evidence of a Giant Early Thames flowing from the direction of Snowdonia, through the Goring gap and then north-east across East Anglia to the North Sea (Fig. 6, *opposite*).

During the Anglian ice age, when sea levels were much lower, the Thames joined the Rhine in what is now the southern North Sea. Ice blocked their flow to the north, and the resultant lake eventually flowed over the anticlinal ridge that extended from the Weald across what is now the Channel. The enormous combined river flowed westwards across the land surface that is now the bottom of the Channel, and reached the Atlantic coast north-west of what is now Brittany.

Thames river terraces

The flanks of the Thames often have a step-like morphology (Fig. 7, *below*).

Above the bedrock are the river deposits and tills, and the products of weathering and mass flow. The river has been down-cutting throughout the Quaternary Period, owing to a relative fall in sea level: the oldest deposits are at the top, the youngest at the bottom.

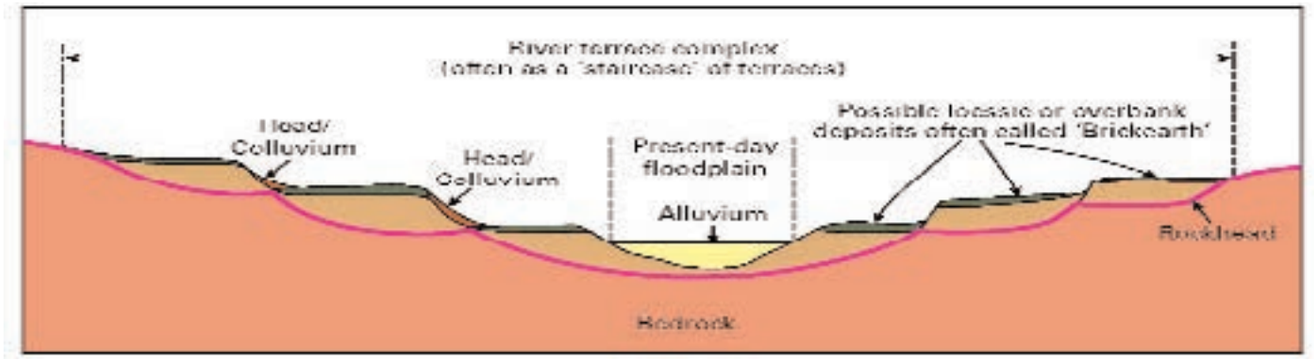

Figure 7 Cross-sectional diagram showing the step-like morphology of the Thames.

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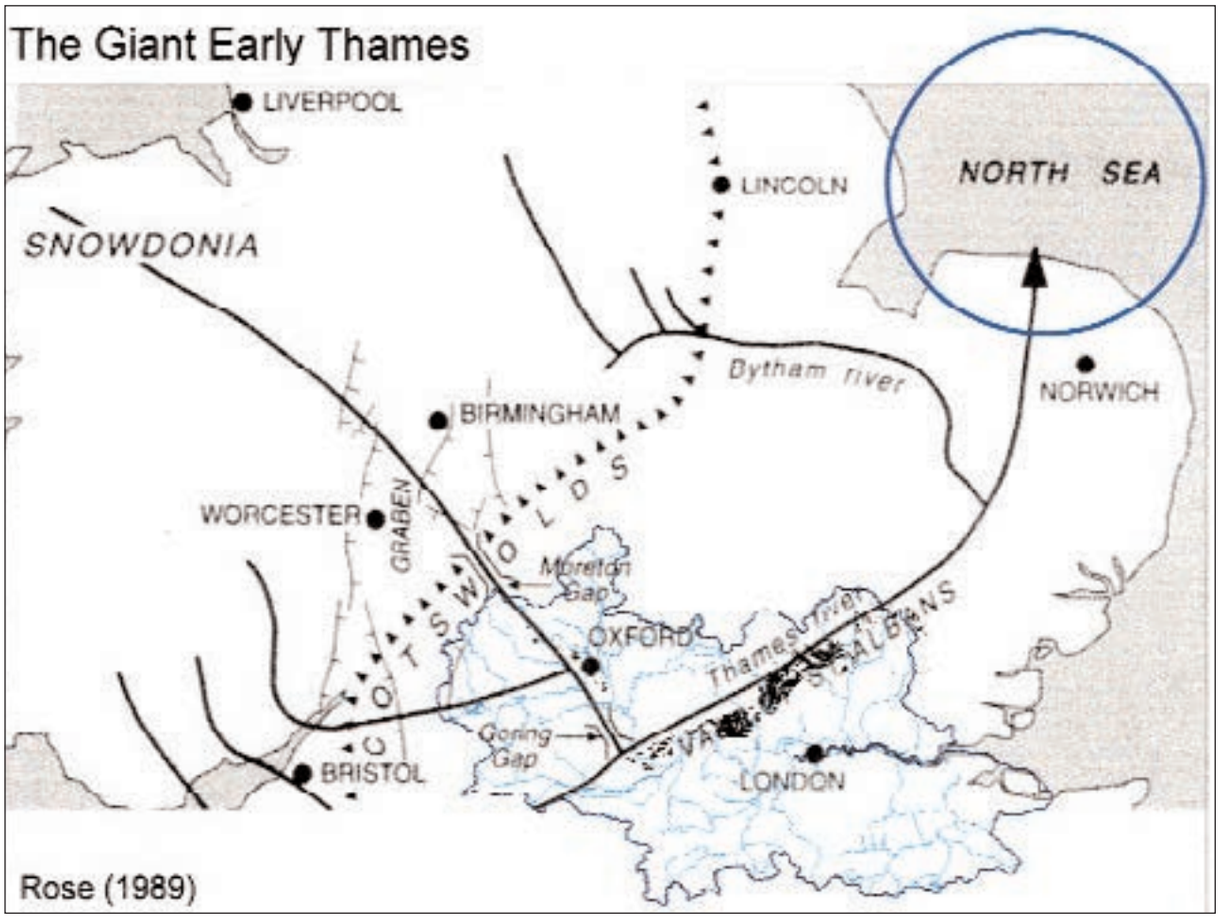

Figure 6 An earler, 'Giant' River Thames flowed from Snowdonia through the Goring gap and north-east across East Anglia.

The Holocene Epoch is dominated by relative sea level rise. This has been 30m in the last 10,000 years, and is currently *c.* 1mm per year: using GPS technology southern Britain is shown to be sinking at *c.* 1.5mm per year, while glacial melting and thermal expansion of seawater currently cause a rise in sea level of *c.* 1mm per year, producing the combined effect of a current relative annual rise in sea level of *c.* 2–3mm. The inevitable result will be more flooding in the lower part of the Thames estuary, and alluvium accretion in the upstream areas.

Acknowledgement

We thank Dr Newell for his informative and well-structured presentation about our part of the country.

The author

Brian Teasdill is the Lectures Coordinator for the OU Geological Society Oxford Branch.

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An introduction to carbonatites and associated rocks with special reference to the intrusive carbonatites of Fuerteventura, Canary Islands

Duncan Woodcock

Introduction

Carbonatites are the products of carbonate magmas. This paper provides an overview of these unusual rocks with their associated alkaline silicate rocks and then looks at examples of intrusive carbonatites exposed in the Basal Complex of Fuerteventura. One location (Caleta de la Cruz) , where carbonatites and associated rocks have been deformed by dextral shearing, is described in detail.

Carbonatites

Carbonatites are 'igneous carbonates': the intrusive and extrusive products of carbonate magmas. The carbonate is usually calcite, but may be dolomite or ankerite. Natrocarbonatites, composed predominantly of sodium and potassium carbonates, also occur but weather rapidly on exposure (Best and Christiansen 2001).

The carbonatites of the Fen Complex of Norway were among the first to be studied in detail. Here the carbonatites occur in association with alkaline silicate rocks and are surrounded by an aureole of about one kilometre wide where the country rocks have undergone an intense sodium metasomatism, known as fenitisation.

The acceptance of carbonatites as a distinct rock type came slowly. The influential American petrologist Daly asserted that carbonatites were nothing more than remobilised limestones; a view that was vigourously supported by the even more influential and dogmatic Bowen. However, a programme of geological mapping in eastern and central Africa by the colonial geological surveys before World War II discovered a number of intrusive carbonatite bodies with almost identical mineralogies and rock associations to the Fen Complex.

Exploration of Kisingiri volcano in Kenya and Napak volcano in Uganda established a clear link between intrusive carbonatite complexes and cogenetic extrusive alkaline silicate rocks. Extrusive carbonatite tuffs and lavas were subsequently discovered at Fort Portal in Uganda. The evidence for extrusive carbonatites was established beyond doubt in the 1960s, when Oldoino Lengai volcano in northern Tanzania erupted a carbonatite lava with an unusual natrocarbonate composition. Oldoino Lengai continues to erupt intermittently, producing carbonatite lavas that have an unusually low temperature of *c.* 450C, a high volatile content and a very low viscosity. Lavas are emplaced as pahoehoe flows that are initially black but rapidly become white on exposure.

The petrogenesis of carbonatites is still not fully understood and is an area of active research. It is generally accepted that carbonatites are the products of the partial melting of a metasomatically enriched mantle, but it is not yet clear whether they are discrete carbonate melts produced directly or an immiscible phase that separates from a carbonate-silicate melt.

There is considerable supporting evidence for an origin involving the phase separation of immiscible carbonate and silicate magmas. Immicibility is observed in model silicate-carbonate systems when studied in the laboratory. Immiscibiliy can sometimes be observed in hand specimens, particularly in extrusive carbonatites, where carbonate inclusions are separated from surrounding silicate glass by a smooth curved, presumably surface tension-controlled interface. Finally, carbonatites are usually found in association with a specific suite of alkaline rocks, which can be interpreted as a conjugate silicate phase.

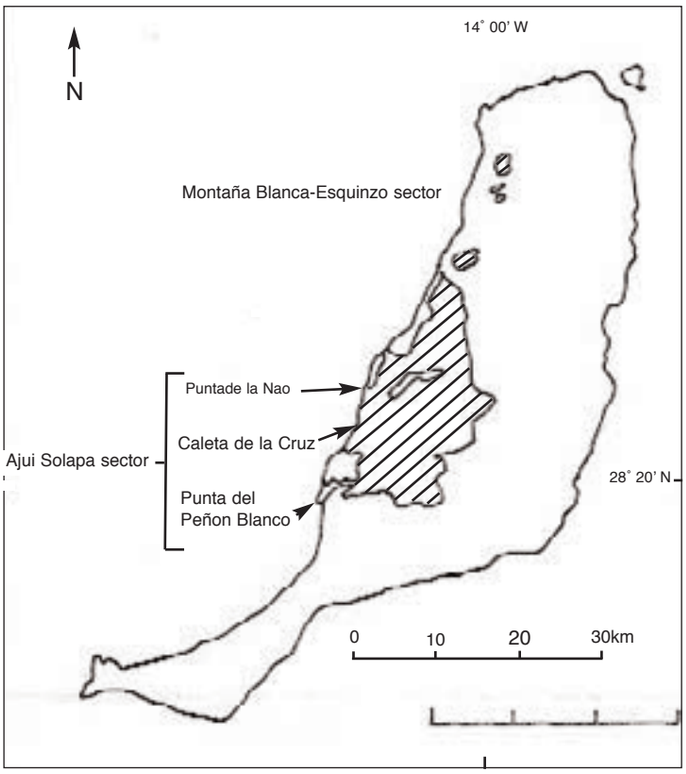

Figure 1 Map of Fuerteventura, showing the location of the Basal Complex (shaded) and the carbonatite locations mentioned in the text.

Carbonatites have unusual minor and trace element compositions to match their unusual major element compositions. They are strongly enriched in rare earth elements to the extent that these often occur in discrete mineral phases rather than within the crystal lattices of common rock-forming minerals. These rare earth-containing minerals include monazite [$CePO_4$], bastnaesite [$(Ce,La)CO_3(F,OH)$] and pyrochlore [$(Ce,Na)_2\ (Nb,Ta)_2O_6(O,OH,F)$]: carbonatites are thus an important source of rare earth elements. In addition pyrochlore is the source of most of the global production of the strategic metals niobium and tantalum (Woolley 1995). These metals are key components in special steel 'superalloys' used in advanced engineering applications such as gas turbines.

Carbonatites are widely distributed in continental settings. They are frequently associated with continental rifts: most of the carbonatite occurrences in eastern and central Africa are associated with the East African Rift Valley. Carbonatites associated with older rifts include occurrences around Kaiserstuhl in the Rhine Valley and the Fen Complex in the Oslo Graben.

Recent discoveries of extensive carbonatite volcanism at Calatrava, Spain and elsewhere in Europe have increased the number of known occurrences of carbonatites (Bailey 2005). These localities contain carbonatites that were previously dismissed as secondary cement or as limestones. Ongoing studies of

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these new carbonatite occurrences will no doubt provide additional insights into carbonatite petrogenesis. In contrast, there are relatively few occurrences on ocean islands, although carbonatites are present on the Cape Verde Islands and the Canary Islands (Middlemost 1997).

A review of the occurrences within the Basal Complex of Fuerteventura forms the remainder of this paper.

Carbonatite occurrences on Fuerteventura

Intrusive carbonatites occur at several locations on Fuerteventura, all within the older rocks of the Basal Complex that is exposed on the western coast and in the western mountains of the island. This Basal Complex is overlain unconformably by the 'shield building' subaeriel lava flows. For an up-to-date overview of the geology of Fuerteventura, refer to Carracedo and Day (2002) and to Carracedo *et al.* (2002).

The Basal Complex contains the oldest rocks on Fuerteventura and comprises two distinct units. The older unit contains a sequence of early Jurassic to mid-Cretaceous pelagic limestones and siliciclastics that overlie early Jurassic pillow lavas with a MORB affinity: this unit is thus the remains of the original ocean crust on which the Canary Islands were subsequently constructed (LeBas *et al.* 1986).

The younger unit of the Basal Complex developed during the submarine volcano or 'seamount' stage. It comprises alkali basaltic pillow lavas and volcaniclastic rocks that were subsequently intruded by a suite of mafic and ultramafic bodies together with an extensive NNE-trending dyke swarm. In places these dykes occupy in excess of 80% of the outcrop and have the appearance of a sheeted dyke complex similar to those seen within ophiolites. This observation led to the initial supposition that the Fuerteventura Basal Complex may be an ophiolite (Gastesi 1973). Subsequent detailed mapping disproved this supposition by showing that the dyke swarm cut the Mesosoic oceanic sediments (Stillman *et al.* 1975).

The submarine volcanic rocks of the Basal Complex were affected by an intense hydrothermal metamorphism caused by the circulation of heated seawater through them. In addition, there was extensive contact metamorphism local to the intrusions that occasionally produced partial melting of the country rocks (Hobson *et al.* 1998; Woodcock 2007). Metamorphic alteration has made it difficult to obtain reliable radiometric dates on many of the rock units within the Basal Complex (Balogh *et al.* 1999; Muñoz 2005).

The carbonatites occur within gabbro-syenite-carbonatite complexes that are emplaced into the submarine volcanic rocks. Figure 1 shows the location of these complexes within the Basal Complex. These 'alkaline-carbonatite' complexes are conveniently grouped into two sectors: a northern Montana Blanca-Esquinzo sector and a southern Ajui-Solapa sector (Muñoz 2005).

The Montana Blanca-Esquinzo sector is exposed in the northern mountains of the Basal Complex, away from the coast. Exposure is relatively poor compared with the coastal exposures discussed below, with much of the outcrop mantled with debris and caliche. The best exposures in this region occur in the 'barrancos': dry valleys cut by the passage of sediment-laden water from infrequent but torrential rainstorms. Even then, exposure can be variable, depending on the vagaries of debris deposition after the last rainstorm. Brief field details for this sector are given in Woodcock (2000) with more detailed accounts in Muñoz *et al.* (2003) and Barrera *et al.* (1981).

The Ajui-Solapa sector is exposed on the coast in the centre of the Basal Complex and has excellent and easily accessible exposures at two locations: Punta de la Nao and Caleta de la Cruz. The exposures at Punta del Penon Blanco are much less accessible: they are described in detail in Fernández *et al.* (1997).

The exposures at Punta de la Nao are described in some detail in Woodcock (2000). Here irregular masses of white, medium- to coarse-grained carbonatite are exposed on a wave-cut platform just above the high water mark. Access can be restricted during periods of high water and curtailed during periods of heavy onshore winds, when the exposure is periodically deluged by heavy waves. The outstanding exposures at Caleta de al Cruz are described in detail below.

Alkaline-carbonatite complex at Caleta de la Cruz

The alkaline-carbonatite complex at Caleta de la Cruz is exposed on a wave-cut platform *c.* 5m above mean sea level, so it can be visited at all states of the tide. The complex has been cut by a NW-trending shear zone, enabling study of the different responses of the carbonate and silicate rocks to the imposed stress field. This location is discussed briefly in Carracedo and Day (2002) and in more detail in Muñoz *et al.* (2003) and in Fernández *et al.* (1997).

Figure 2 *(overleaf)* comprises a sketch map of the location, drawn from my own field survey, aided by the excellent satellite image coverage from GRAFCAN, which is currently available on Google Earth. The lithologies exposed comprise alkali gabbros and pyroxenites intruded by syenites and carbonatites, in turn cut by a series of NNE-trending dykes (Fig. 3).

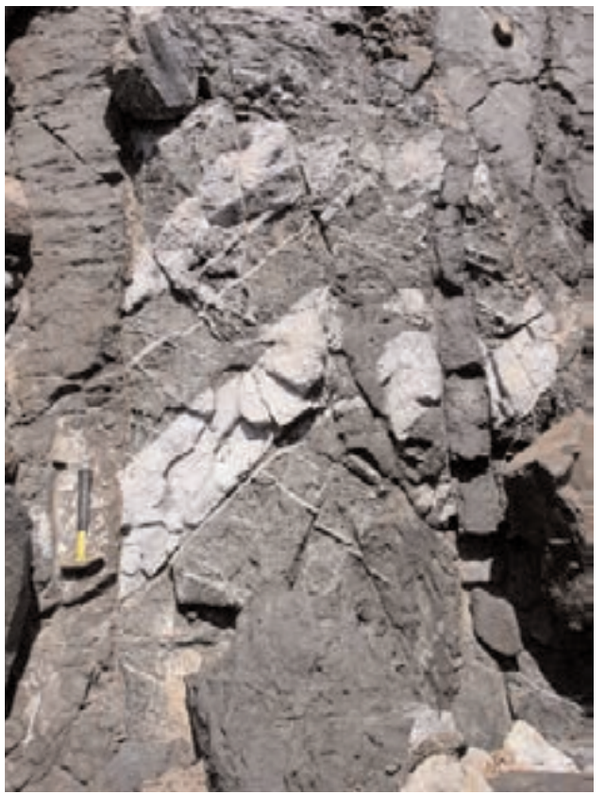

Figure 3 Brittle deformation in alkali gabbro (darker) intruded by syenite veins (lighter). The later subvertical basaltic dykes are undeformed.

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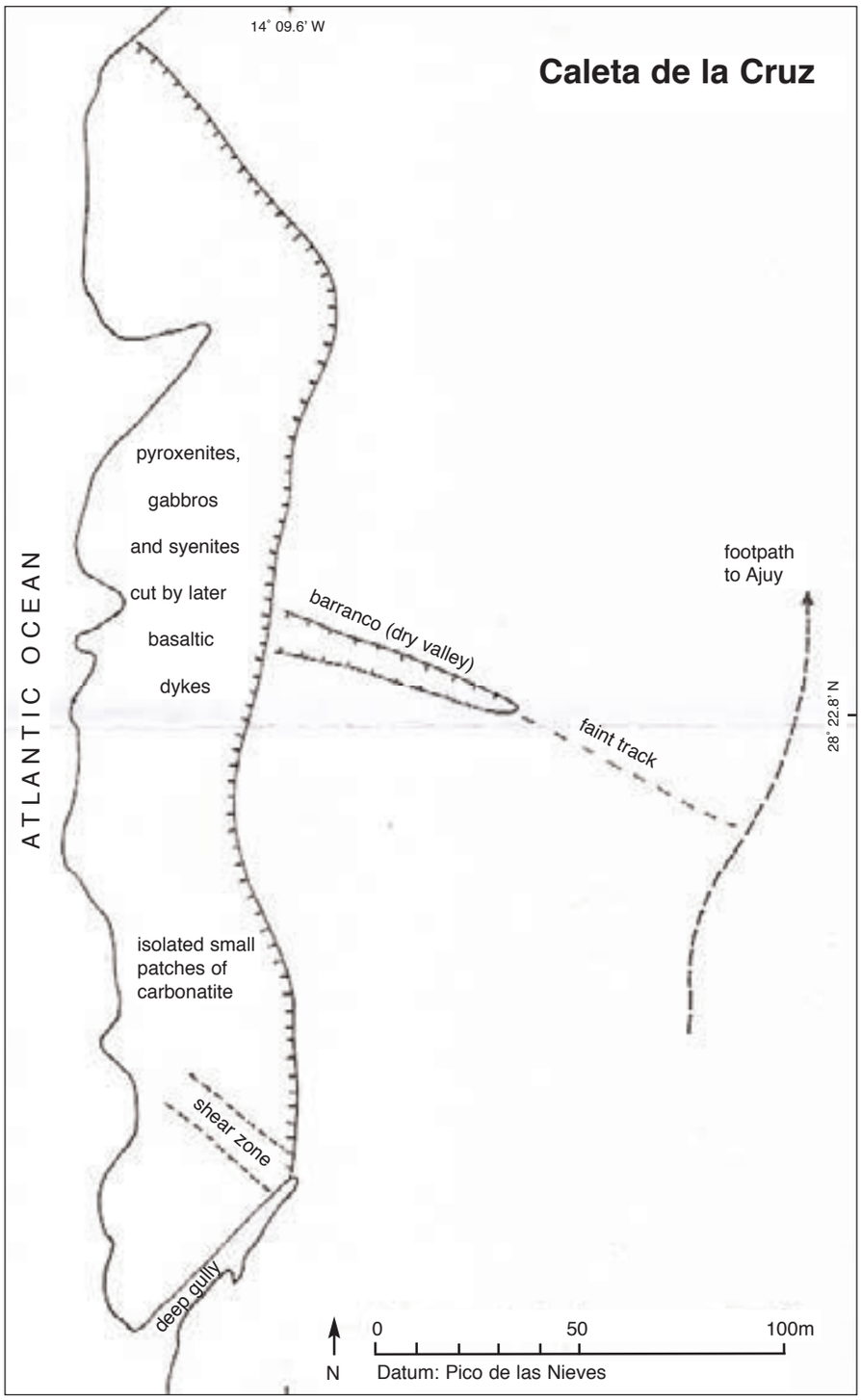

Figure 2 Sketch map of the exposures on the wave-cut platform at Caleta de la Cruz (drawn from GPS survey [March 2008] and from Google Earth image).

The alkali gabbros are medium grey, coarse-grained rocks. In thin section the mafic minerals can be identified as biotite mica together with the yellow-green/blue-green pleochroic pyroxene aegirine. The main felsic mineral is a rather turbid plagioclase feldspar. Accessory minerals include sphene and apatite. The pyroxenites have a similar mineralogy but a much greater proportion of mafic minerals.

The gabbros and pyroxenites are intruded by a porphyritic syenite. This is a light grey speckled, coarse-grained rock, often with prominent feldspar phenocrysts that display simple twinning, suggesting an alkali feldspar (Fig. 4). In thin section the alkali feldspar is slightly altered, but displays a perthitic ex-solution texture. Mafic minerals comprise *c.* 10% modal and include biotite and aegirine. Accessory minerals include sphene, apatite and an opaque mineral.

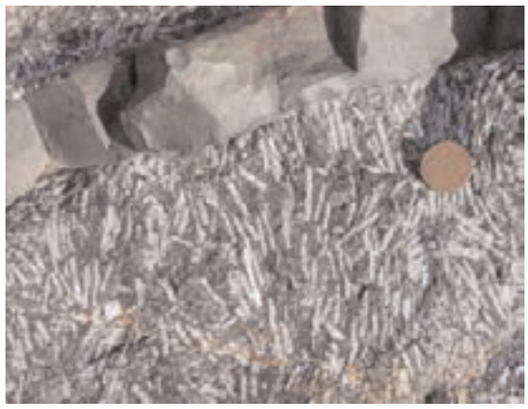

Figure 4 Porphyritic syenite with prominent tabular phenocrysts of simple-twinned alkali feldspar, from Caleta de la Cruz (diameter of coin 20mm).

The carbonatites occur in small patches away from the shear zone but are most prominent within the shear zone. They are white or light grey, coarse-grained rocks with patches of darker minerals present. In thin section they comprise mainly lamellar twinned calcite with patches of phlogopite mica. Accessory minerals include apatite and a sprinkling of small cubes of a very high relief, golden brown mineral, probably pyrochlore.

The shear zone occupies a NW-trending zone *c.* 10m wide at the south end of the wave-cut platform. Shearing has affected the gabbros, pyroxenites and carbonatites, but appears to have been focussed in a relatively carbonatite-rich zone; presumably because the carbonates are less competent than the silicate rocks (Fig. 5). The shear zone is cut by NNE-trending dykes that are generally undeformed.

Deformation is considered to be related to the emplacement of a large pluton immediately inland. Dextral shear occurred at the relatively low

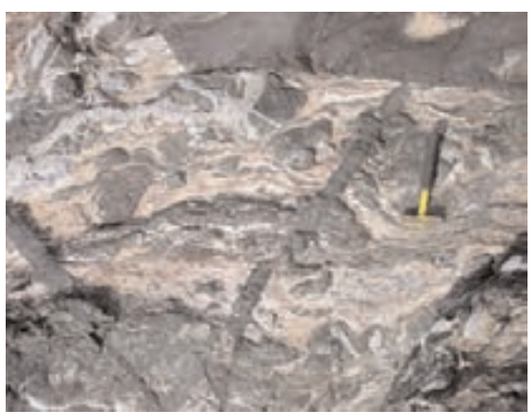

Figure 5 Carbonatite-rich zone within the shear zone cut by a later basaltic dyke, Caleta de la Cruz.

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Figure 6 Ductile deformation of carbonatite round a 'brittle' block of syenite, Caleta de la Cruz (diameter of coin 20mm).

temperature of 400C to 500C (Muñoz *et al.* 2003). The silicates have responded in a brittle manner while the less competent carbonates show ductile deformation (Fig. 6).

Mafic inclusions within the carbonatite generally show a darker rim, typically 5–10mm thick, at the contact with the carbonatite matrix (Fig. 7). This was produced by reaction between the pyroxene of the mafic inclusion and the carbonate to produce a dark aggregate of diopside and phlogopite mica. (Carracedo and Day 2002; Fernández *et al.* 1997). The presence of the phlogopite enhanced the ductility of the margins of the inclusions: many of the inclusions have been deformed and have asymmetric tails like porphyroclasts (Fig. 8, *overleaf*).

A thin section of an inclusion shows the margin to be dominated by the pale red-brown weakly pleochroic phlogopite mica. Away from the margin the phlogopite grades into a more strongly pleochroic biotite (phlogopite and biotite form a solid solution series). The core of the inclusion contains the mafic minerals biotite and aegirine. There are patches of a garnet, probably melanite, with a very low birefringence between crossed polars. Euhedral crystals of the garnet are zoned with colourless cores and very light yellow-green rims. Accessory minerals include sphene plus abundant apatite.

The exposures on the wave-cut platform at Caleta de la Cruz are outstanding and are recommended for inclusion on any geoitinerary of Fuerteventura.

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Figure 7 Mafic inclusions within carbonatite showing the darker aggregate of diopside and phlogopite produced by the reaction of pyroxene with carbonate, Caleta de la Cruz (diameter of coin 20mm).

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Acknowledgement

The historical information on carbonatites was derived from notes taken during a talk given by Dr Alan Woolley at a recent symposium on carbonatites organised by the Manchester Geological Association.

The author

[check earlier articles for by-line info]

Figure 8 Mafic 'porphyroclast' with asymmetric tails indicating formation during dextral shear, Caleta de la Cruz (diameter of coin 20mm).

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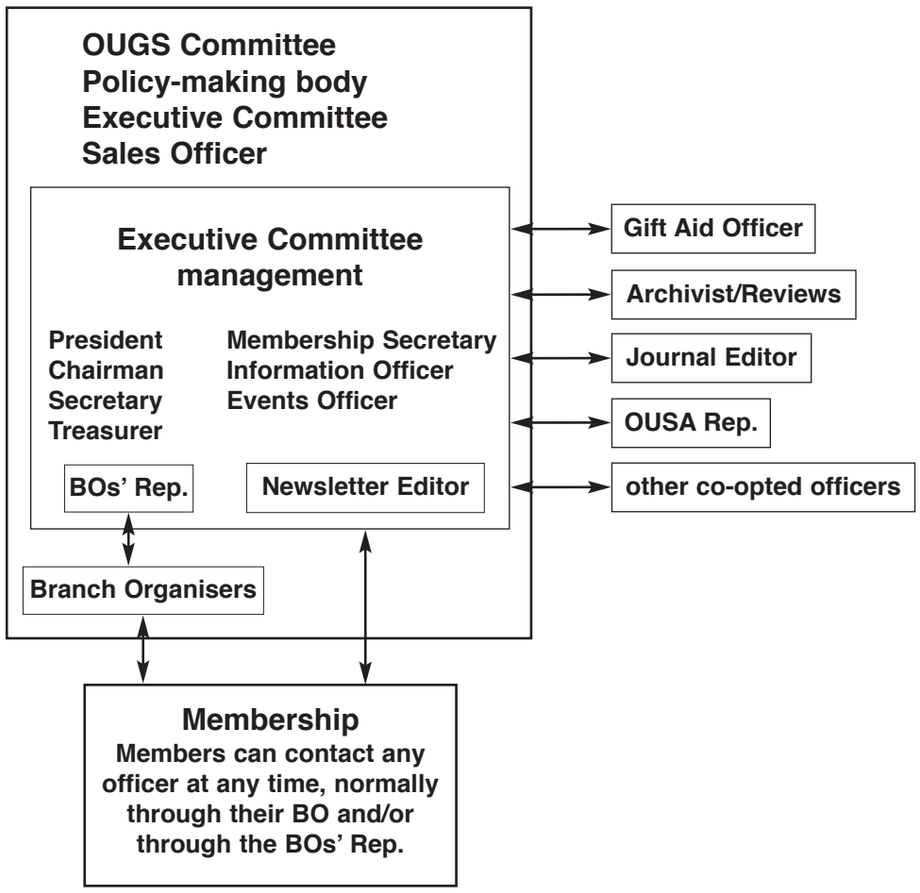

Category A — Geologically Inspired Landscape: Winner, "The Oberaar Glacier", photographed by Josephine Brown

*The Oberaar Glacier is one of many glaciers that network across the high Aar Massif Mountains north of the Upper Valais in the Swiss Alps. This is the area where Louis Agazzi and companions performed glacial studies in the early 1840s. His ascent of the Jungfrau began with climbing to the top of this glacier (*OUGS Journal *29 (2) 2008, 61). Nowadays, the Oberaar reservoir, at 2303m, is the highest large reservoir of the eight constituting the Grimsel hydroelectric system. Waters from this system flow northward, eventually joining the Rhine east of Basle. The waters of the Rhone Glacier, 9km to the east, flow west to the Mediterranean.*

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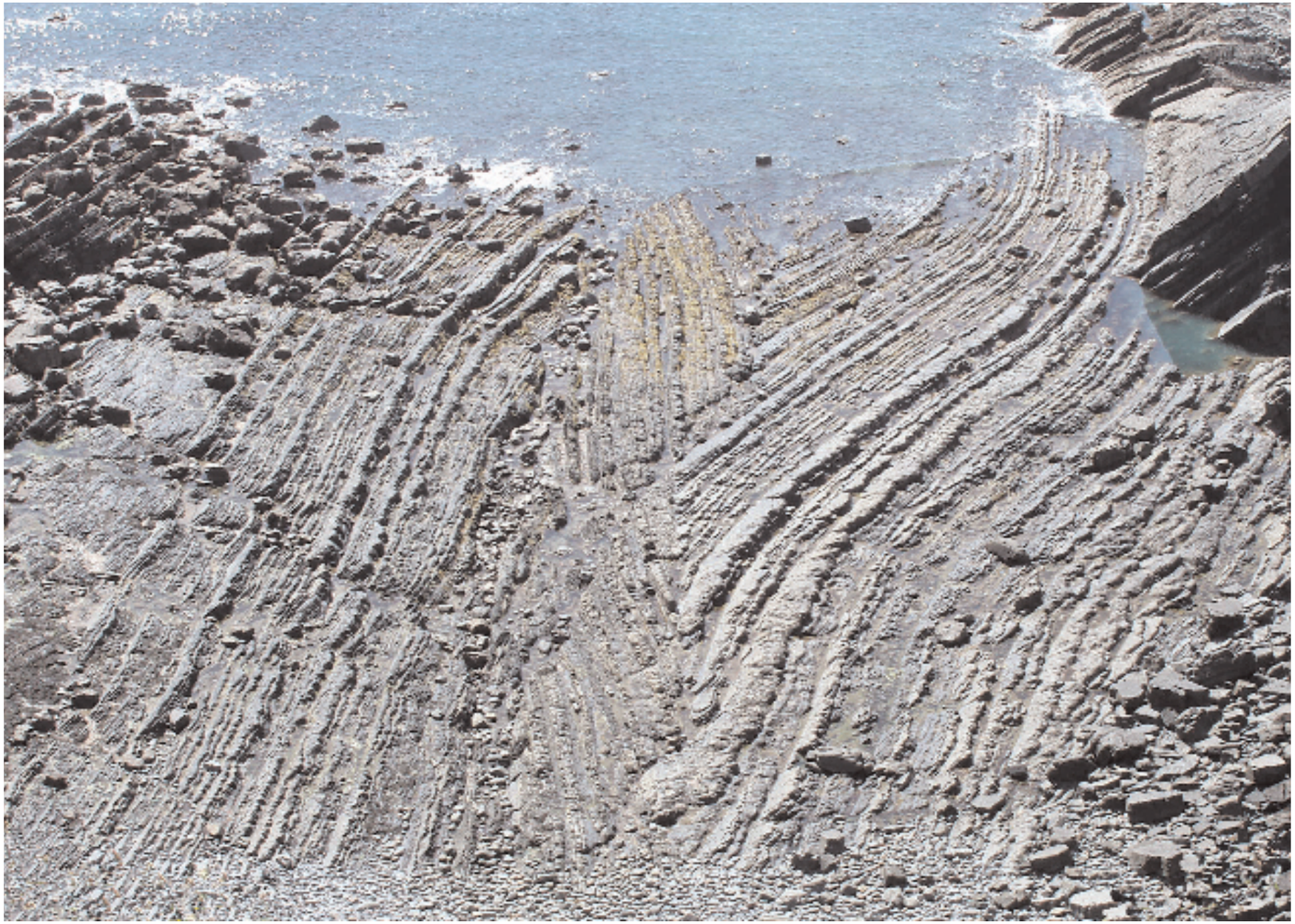

Category B — Geological feature or structure: Winner, "Wavecut platform, Hartland Point, N. Devon", photographed by Linda McArdell

The heavily folded and faulted carboniferous limestones and sandstones for which Hartland Quay is famous are exposed at Broad Beach between the Quay and Hartand Point, where the waves have worn them flat, eroding the cliffs at c. 10cm a year to give this wide shore platform. The folding is Variscan.

"Wavecut platform" was also the Popular Vote Winner for 2009.

Category C — Industrial geology: Winner, "Holmbush Mine Engine Houses, Kelly Bray, Cornwall", photographed by Chris Popham

Holmbush mine possibly began work as early as 1600 on the north–south (cross-course) lead lode. The galena gave good yields of silver and the lode is one of the few in the south-west mining region from which native silver was recorded.

These engine houses stand beside the Kelly Bray to Stoke Climsland Road and were partially restored in 2004–5. They date from the early 19th century, when the mine was expanded to work on the five east–west copper and tin lodes. The engine house to the rear shows typical construction, with the chimney built against the 'picture' wall of the house and the 'bob' wall — where the arm of the beam engine would have rested, blank and closest to the photographer. The exact relationships between the foreground chimney, the building behind it and the engine house on the right are unclear, although the foreground house certainly housed a steam engine, as the mounting blocks are still in situ.

The tips contain abundant arsenopyrite, pyrite, chalcopyrite and fluorite, with a little galena and some siderite. This is also the type locality for the mineral 'Holmbushite', also known as Francolite, but more properly a variety of Carbonate-Fluorapatite, which is found as pale, densely-packed needles lining cavities.

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(above left) Category A: Highly Commended, "Tufa Columns, Mono Lake, California", photographed by Elaine Burns

Mono Lake, east of California's Sierra Nevada Mountains at the edge of Nevada's arid Great Basin, is a saline lake with twice the salinity of the Pacific Ocean. Fed by freshwater mountain streams and springs, it has no outfall. Islands in the lake are the result of relatively recent volcanic activity, including impressive boulder- to pocket-sized nodules of obsidian (protected from removal). Calcium carbonate deposits precipitate where freshwater springs meet the lake's saltwater carbonates, over time forming intricate tufa towers. Increasing exposure owing to excessive water diversion from feeder streams by the Los Angeles Department of Water and Power has led to fears for their loss, and formation of a local pressure group to work with LA authorities to reduce water extraction by 80%, and a rise in the lake level.

(above right) Category B: Highly Commended, "Striated and polished granite above the Rhone Glacier", photographed by Josephine Brown

Late October afternoon sun illuminates the effects of the Rhone Glacier on the Aar granite. Observations from the new Lötschberg tunnel suggest that the Aar Massif may be a massive thrust sheet rather than a large block of crystalline basement, which has been pushed up through overlying sediments. The glacier is receding at an alarming rate and cannot now be seen flowing over its rocky ledge when viewed from the valley below. Worryingly, a small lake formed at the snout in 2006. The photograph was taken half way down from a sign denoting the glacier's height in 1947 to its present elevation.

(left) Category C: Highly Commended, "Innovative Wall, Tintagel, Cornwall", photographed by Linda McArdell

This section of wall is on the footpath to Tintagel Castle, just as it leaves the village. The chunk of folded rock is probably from the Hartand area, where the heavily folded and faulted carboniferous limestones and sandstones of the cliffs are slowly being eroded. Storm-force waves in that area are known to be able to move 20-ton boulders, so shifting this breeze-block-sized piece several miles south to Cornwall is not suprising — unless a weary geologist got tired of carrying their samples home and dropped it here for a stone waller to use! It is quite different from the local schists and phyllites.